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cf. also East Malling report 1956, p. 149
being abstr. by Kirby Ford.

GREENHOUSE TESTING OF FUNGICIDES AGAINST *BOTRYTIS* ROT (GREY MOULD) OF STRAWBERRY AND OTHER SOFT FRUITS

By M. H. MOORE and R. P. TEW
East Malling Research Station, Kent

GREY MOULD, caused by the fungus *Botrytis cinerea* Pers. *ex* Fr., varies greatly in destructiveness in response to seasonal conditions. In wet weather towards the end of May, 1941, for instance, when early strawberry blossoms at East Malling had been killed by frost, Grey Mould developed freely on the dead blossoms, and it seemed that the experience of 1937, when there was severe fruit-rot (Wormald and Harris, 1938), might well be repeated. Yet field trials, both in 1941 and 1942, on the variety Royal Sovereign, to compare thiram, salicylanilide, and soda-soap sprays, gave inconclusive results, for dry weather after blossom proved unfavourable for fruit-rot to develop. However, in 1942, a laboratory experiment, in which ripening strawberry fruits were dipped in preparations of these chemicals, then inoculated with a spore-suspension and kept in a moist atmosphere, indicated some promise from thiram (0·1 per cent.) and salicylanilide (0·25 per cent.).

Following severe *Botrytis* rot in the field in 1953, this fruit-dipping technique was elaborated for further screening tests in 1954, to be described in the present paper. A similar method was used by Horn (1952), as was also a glass-slide screening method, in both of which the fungicide was, however, mixed with the spore-suspension. A glass-slide method was used also by Frick (1955). The results of these tests, and of field trials in the U.S.A. (Horn, 1952; Powell, 1952 and 1954) and in Britain (Kirby *et al.*, 1955; Marsh *et al.*, 1955) showed that the new organic fungicide, captan, held promise for checking Grey Mould outbreaks.

Botrytis rot often occurs in unstrawed beds where the tip of a strawberry fruit rests on moist soil, but infection at the calyx end was a prominent feature of the severe field outbreaks of the disease in 1953 and 1954, and indeed of those in former years. Dense fructifications of *Botrytis cinerea* were present on the pedicels, calyces, and stamens, and on persistent dead petals as the fruits developed. Evidently many fruit-rot lesions had originated either from direct contact of these organs with the fruits or from spores washed or splashed on to them.

An attempt was made to simulate these conditions in the following experiments.

EXPERIMENTS.

MATERIALS AND METHODS.

Chemicals.

The chemicals selected for study in two exploratory experiments, A and B, with appropriate controls, were :

"Home-made" Bordeaux mixture	0·4 per cent. copper sulphate. 0·6 per cent. hydrated lime.
Copper oxychloride	0·025 per cent. copper.

Lime-sulphur	2 per cent. by volume.
,,	undiluted.
Elemental sulphur	0·5 per cent. S.
,, ,,	sublimed, as a dust.
Captan (N-trichloromethylthiotetrahydrophthalimide)	0·1 per cent.
,,	0·2 per cent.
Ziram (zinc dimethyldithiocarbamate)	0·2 per cent.
Thiram (tetramethylthiuram disulphide)	0·2 per cent.
PCNB (pentachloronitrobenzene)	0·2 per cent.
Salicylanilide	0·2 per cent.
,,	0·4 per cent.

The most promising of these materials were then further compared in subsequent experiments, C-G.

Commercial preparations of lime-sulphur, dispersible sulphur, sublimed sulphur, and copper oxychloride were used. The other chemicals were formulated either for aqueous dispersion as 50 per cent. wettable powders or, in the later experiments, for dry application as 10 per cent. dusts. The wettable powders were produced by grinding the amount of chemical needed to provide the required concentration and volume of aqueous dispersion, with an equal weight of china clay and 4 per cent. by weight (i.e., 2 per cent. by weight in the final powder) of saponin. The mixture was then passed three times through a 200-mesh sieve and suspended in the required volume of water containing 0·01 per cent. sodium dioctyl sulphosuccinate as wetter. Dusts were prepared by grinding together equal weights of chemical and talc, passing this mixture three times through a 200-mesh sieve before dilution with the remainder of the talc (eight times the weight of toxicant) and mixing by three passages through a 30-mesh sieve.

Treatment of host.

Ripening fruits of Royal Sovereign strawberry with no apparent infection or damage were selected from a field sample. With chemicals tested as aqueous dispersions, the fruits were dipped in the appropriate dilutions with occasional stirring. To ensure thorough wetting, each fruit, held by its stalk, was immersed over the calyx and withdrawn rapidly five times. The four fruits comprising each experimental unit were allowed to drain on filter paper in a shallow dish until air-dry. The dishes were then randomized on the floor of a glasshouse incubation chamber.

Raspberry and blackberry fruits were used in later tests when strawberries were no longer readily available. The procedure was the same, but eight instead of four fruits were included in each dish.

For experiments in which dusts were compared with aqueous dispersions, fruits to be dusted were pre-treated by dipping them in a 0·01 per cent. aqueous solution of the wetter, and their surfaces were air-dried. Thus any tendency there might have been for the spore-suspension to spread less easily on the dusted fruits was obviated. The four (or eight) fruits were gripped by their stalks in a spring clip holding them in line without touching each other. The dust was directed in small clouds towards the fruits held in " still " air, and the clip was then reversed to present the other side of the fruits. The use of a glass throat-spray atomizer instead of a small powder bellows facilitated uniform distribution of dust by making it visible before it was dispersed.

Method of inoculation.

The first experiment was designed to include two distinct methods of inoculation, to simulate natural infection arising: (*a*) initially between calyx and fruit by contact of the latter with infected floral organs, and (*b*) from spores washed or splashed on to the exposed surfaces of the fruits from infected floral organs or other sources.

For method (*a*), a small piece of the flesh of rotting strawberry fruits, previously infected by inoculation from a culture of *Botrytis cinerea* grown on surface-sterilized Edward VII apples, was inserted between the calyx and the fruit, care being taken not to wound the fruit in the process. For this method, the inoculations were made before the dishes of fruit were placed in the moist chamber. The first experiment showed, however, that this method of inoculation was much too drastic for test purposes, and it was abandoned in favour of spore-inoculation (*b*), for a treatment that could protect the surface of the ripening fruit from infection might also protect the floral organs if applied early enough. In the field, the presence of infected petals or stamens between calyx and ripening fruit makes control by chemical sprays very difficult, especially in conditions of high humidity favourable to the fungus.

For method (*b*), a dense spore-suspension of *B. cinerea* was made by swirling infected fruits of the appropriate kind in distilled water, preferably containing the wetter to disperse spore-aggregates. The treated but now surface-dry fruits, already in position in the moist chamber were then thoroughly sprayed with this suspension from the atomizer. Spore-viability was tested after some of the spore-suspension had been kept in the moist chamber for about 24 hours.

Environment.

The floor of the incubation chamber was covered with a layer of moistened peat. After the fruits had been inoculated, the filter-papers in each open dish were moistened by just saturating them with distilled water, and the front of the incubation chamber was closed. The filter-papers were remoistened if necessary, and the fruits were lightly sprayed with distilled water during the incubation period. These conditions proved to be very favourable for infection.

Recording.

Infections could sometimes be detected within 24 hours after incubation, but as some of these were on the untreated and uninoculated control fruits, which had temporarily been put into another chamber while the rest were being inoculated, the fruits had evidently already been contaminated in the field. The degree of pre-contamination was assessed by reference to the uninoculated controls; surface-sterilizing was not attempted, for this had proved rather unsatisfactory with blackberries on an earlier occasion (Moore and Talboys, 1953). Infections by a species of *Mucor* were encountered once when the dishes had been covered with moistened blotting paper, so the covering was thereafter omitted.

Detailed recording usually began on the second day after inoculation. Lesions were counted daily and the infected fruits were then removed to minimize the risk of secondary infection.

Note.—Each treatment was replicated four times in experiment A, twice in C, and five times in the rest. The fruits used were: Royal Sovereign strawberry (experiments A-C); Auchincruive Climax strawberry (D); Lloyd George raspberry (E and F); wild blackberry (G.)

RESULTS.

Experiments A and B.

In A, the spore-suspension was dropped on to the fruits from a glass rod ; in subsequent experiments it was sprayed on. In both A and B, the untreated control fruits were inoculated without first being dipped in the solution of the wetter, and the spore-suspension remained on them in globules. This difficulty was satisfactorily overcome in the later experiments by first dipping the untreated fruits in the solution of the wetter, as for fruits to be dusted.

The copper sprays showed little merit, and dispersible sulphur and lime-sulphur failed to sustain early promise. The latter, when used undiluted, failed both as a fine spray and as a dip ; dipped fruits in fact developed almost complete coverings of fungal growth (*Penicillium* sp. as well as *Botrytis*). This rigorous treatment had evidently changed the character of the fruit surface, which was decolorized and seemed as if baked or scalded. Sulphur dust, which is commonly used on strawberries for the control of Mildew (*Sphaerotheca humuli*), showed to better advantage than the "liquid" sulphurs, yet offered insufficient promise to justify further investigation as a control measure solely for *Botrytis* rot. Pentachloronitrobenzene, which as a 20 per cent. dust gave some control of *Botrytis cinerea* on lettuce (Last, 1952), was not effective at 0·2 per cent. in aqueous dispersion as a protectant for strawberry fruits. Frick (1955) showed that, at 0·01 per cent., it did not inhibit the spore-germination of this fungus on glass slides.

The most promising materials were salicylanilide, especially at 0·4 per cent., thiram at 0·2 per cent., and captan at 0·2 per cent. These three materials were therefore chosen for further testing (experiments C-G), each as a 10 per cent. dust and as a 0·5 per cent. aqueous dispersion (Table I).

Experiments C-G.

Table I.

Results of comparing salicylanilide, captan, and thiram as dusts and aqueous dispersions.

Treatment		Mean no. of infections per :				
		4 fruits Experiment :		8 fruits Experiment :		
		C	D	E	F	G
10% Salicylanilide dust			1·6	11·0	8·4	13·8
0·5% Salicylanilide aq. disp.		2·6	1·6	6·0		7·4
10% Captan dust			4·6	8·2	9·0	15·8
0·5% Captan aq. disp.			3·2	4·2		7·8
10% Thiram dust				4·0	9·2	17·0
0·5% Thiram aq. disp.				2·8		3·8
Talc only (formulating material for dusts)			3·6	15·2	10·8	16·8
China clay, saponin, and wetter (formulating materials for aq. disp.)		6·2	4·8	13·2		13·0
Formulating materials for aq. disp. (as above)	Not inoculated		2·8	6·8		16·0
Untreated fruits	Not inoculated	4·4	2·4	8·0		16·6
Sig. diff. (P=0·05)		2·8	2·9	4·3		6·0

DISCUSSION AND CONCLUSIONS.

As the season progressed, fruits brought in from the field carried increasing natural spore-contamination, as shown by the values for infection on the uninoculated controls. It may be partly for this reason that there was a noteworthy contrast between the results yielded, especially by the dusts, in experiments E and G, for they were in fact duplicates, though made on different kinds of fruit. Similarly, the results of experiment F, which was a comparison of the dusts only, and in which the fruits were not " surfaced " by first dipping them in the wetter, did not reflect the results from experiment E, but were more nearly like those from G, although these particular treatments were identical in all three experiments.

It is clear that the treatments were liable to act both as disinfectants and protectants, and that the dusts were less effective than the aqueous dispersions in dealing with pre-contamination. Thus in experiments E and G, when results from the three fungicides are taken together, the dusts proved significantly (P=0·001) inferior :

	Uninoculated fruits	Inoculated fruits treated with :		Sig. diff. (P=0·05)
		Dusts	Aqueous dispersions	
Experiment E ..	7·4	7·7	4·3	1·3
Experiment G ..	16·3	15·5	6·3	3·9

There was, however, clear evidence from experiment E, in which pre-contamination was of a lower order and more emphasis was on protectant action, that not only each of the aqueous dispersions, but each of the dusts, gave significant control. When the results shown in this experiment by dusts and dispersions are taken together, the three fungicides differed significantly (P=0·001) from each other and from the formulating materials, thus :

	Inoculated fruits treated with :				Sig. diff. (P=0·05)
	Formulating materials	Salicylanilide	Captan	Thiram	
Experiment E ..	14·2	8·5	6·2	3·4	1·6

In the parallel experiment on wild blackberry fruits (G), the results showed that only thiram dispersion (3·8) differed significantly from the corresponding formulating materials (13·0), though salicylanilide (7·4) and captan (7·8) came very near to it. Each of the dusts failed in this experiment, in which the fruits were already heavily contaminated before inoculation.

As *Botrytis cinerea* fructifies rapidly in favourable conditions, both eradicant and protectant action are likely to be brought to bear in controlling Grey Mould in the field. When the results are viewed as a whole, therefore, it is permissible to conclude that sprays are more likely to be effective than dusts in practice, especially where the fungus has already established a footing.

Thiram is likely to prove superior both to captan and to salicylanilide, and these two would probably give approximately similar control if they have similar weathering properties, which is a subject for field experiment. These generalizations presuppose, of course, that the fungicide dispersions would be used at equivalent concentrations of active ingredient, and that the method of applying them would be equally comparable.

Marsh, Martin, and Crang (1955) have shown that there is a risk of ultimate taint where ripening strawberry fruits are sprayed in the field with either captan, or, more so, with thiram, and later canned. There is as yet no evidence to show whether or not this holds good for sprays applied at blossom-time or soon afterwards.

SUMMARY.

A greenhouse method of using ripening soft fruits for testing fungicides against *Botrytis* rot (Grey Mould) is described. It is based on dipping a field sample of fruits in, or dusting them with suitably formulated chemicals, then inoculating with a spore-suspension of *Botrytis cinerea* and incubating in a moist chamber.

Of several chemicals, compared either as aqueous dispersions or as dusts, thiram was superior to captan and to salicylanilide, each at 0·5 per cent. of active ingredient. The dispersions were each more effective, especially as disinfectants, than 10 per cent. dusts.

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STRAWBERRY *BOTRYTIS* ROT (GREY MOULD) CONTROL : A FIELD TRIAL OF CAPTAN AT EAST MALLING

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If wet weather prevails when strawberries are ripening, serious losses may occur from *Botrytis* rot (*Botrytis cinerea* Pers. *ex* Fr.). Strawing does not prevent infection, especially if the petals have been subject to attack, and protection of the ripening fruits with a suitable chemical would seem to offer the best hope of avoiding such losses. The chemical must be non-toxic both to the plant and to the consumer and must not taint the fruit ; these desiderata rule out many fungicides, including the mercurials and also dinitrophenol and chlornitrobenzene compounds. Of many others, as shown by laboratory tests (Frick, 1955), only certain groups of fungicides derived from dithiocarbamic acid, and the new fungicide, captan (SR406 ; N-trichloromethylthiotetrahydrophthalimide), are likely to be effective in practice. Recently, Moore and Tew (1955) have shown by a laboratory fruit-dipping technique that thiram, captan, or salicylanilide, at 0·5 per cent. of active ingredient, greatly reduced infection.

Experiments in the U.S.A. with captan have shown that under their conditions considerable control can be achieved in the field with a 50 per cent. wettable powder. Powell (1952) reported experiments with two varieties at different sites in Illinois. At the first site, two applications, on 23rd April (first bloom) and 15th May, at 2 lb./100 U.S. gallons and 460 U.S. gallons/acre, gave 40-50 per cent. reduction in rotted fruits on 29th May and 5th June ; ferbam was also effective. At the second site, captan was not used but again ferbam was effective. Dichlone (2:3-dichloro-1:4-naphthaquinone) gave some reduction in infection but was very phytotoxic. Zineb was ineffective.

Horn (1952) in Louisiana gave seven weekly applications of 50 per cent. captan at 6 lb./100 U.S. gallons and 270 U.S. gallons/acre ; on the sprayed plots, the number of rotted fruits was reduced by half, and the number and weight of non-rotted fruits, as well as the yield per acre, were at least two-thirds greater than from the unsprayed plots.

More recently, Powell (1954) used 8 lb./100 U.S. gallons and about 80 U.S. gallons/acre (horizontal boom), on 14th and 28th April, and 6th (full bloom), 12th and 19th May ; picking began on 24th May. Sampling on 22nd May showed that captan plots had approximately 75 per cent. less rotted fruits ; the yield from the sprayed rows averaged 78 per cent. more than that from the unsprayed. Moreover, fruit size was increased, treated fruits averaging 92 per quart compared with 123 for untreated fruits. This was in agreement with impressions recorded by Horn (1952). When placed in storage for 48 hours, the untreated fruits showed four times as much rotting as the treated.

The trial reported here was begun in 1953 at East Malling, and repeated in 1954, on the varieties Royal Sovereign and Auchincruive Climax, but results on the latter were invalidated by the effects of transient yellows and streak.

Lay-out and Treatments.

Sixteen plots were planted in autumn, 1951 ; each consisted of four rows of 12 plants, two rows of each variety, 48 plants in all, at 18 in. apart with 3 ft. between the rows, and surrounded by a complete guard-row. The plants were de-blossomed in spring, 1952.

Three pairs of treatments were compared :

(1) standard spring fertilizer and summer fertilizers ;
(2) irrigation by hose and no irrigation ;
(3) fungicide sprays and no fungicide sprays.

There were eight replications of any one of the treatments, and two replications of each combination for studies of interaction.

Fertilizer treatments had no apparent interaction with the fungicide treatments, and will not be discussed in this paper. Irrigation of strawberries at East Malling has had a beneficial effect in many years (Wilson, 1954), but has sometimes increased rotting of the fruits ; the interaction with the fungicide treatments is therefore of special interest. The timing and amount of irrigation under (2) were based on calculated soil moisture deficits and will be discussed elsewhere.

Weather.

Rainfall during the eight days 27th May to 3rd June, 1953, exceeded an inch and was associated with a daily average of only 4·6 hours of sunshine. A further 0·36 in. fell on 11th June and was followed by dull weather and relative humidities exceeding 80 per cent. for a week ; picking began on 12th June.

In 1954, dull weather prevailed in May and June, and 2·32 in. rain fell between 5th and 13th June, with relative humidities between 70 per cent. and 90 per cent. up to the 19th. The season was fully a week later than 1953, picking beginning on the 21st.

These conditions were very favourable in both years for *Botrytis* attack.

RESULTS.

1953. A wettable powder containing 50 per cent. captan was applied by lance on 29th May (after petal-fall and immediately after strawing down) at 2 lb./100 gallons (0·1 per cent. active ingredient) and about 300 lb. p.s.i. pressure. A second application at the same strength was made on 9th June (earliest fruits nearly ripe) with another machine giving only 70 lb. p.s.i. On the first occasion, 40 gallons were used on the eight sprayed plots, which together with guard rows covered a total of 300 sq. yds., and 33 gallons on the second occasion. The sprays were applied to the whole area and not only to the plants.

The crop of Royal Sovereign is shown in Table I in the following grades :

Grade 1—sound fruit above $\frac{7}{8}$ in. diam.
Grade 2—smaller sound fruit.
Grade 3—damaged and rotted fruit.

No attempt was made to separate rot due to *B. cinerea* from other rots or damage.

The total crops from sprayed and unsprayed plots did not differ significantly ; neither did the marketable crops (Grades 1 and 2) nor the percentage of Grade 1 in

TABLE I.

Mean crop weights for Royal Sovereign in kg. per plot (24 plants) in 1953.

	Sprayed with captan			Unsprayed		
	Grade			Grade		
	1	2	3	1	2	3
Irrigated	3·36	1·97	2·22	2·60	1·52	2·44
Non-irrigated	3·47	1·79	2·09	2·99	1·51	2·13
Mean	3·41	1·88	2·15	2·79	1·51	2·28
Total crop	7·44			6·58		
Marketable crop	5·29 (71·1%)			4·30 (65·1%)		
Percentage Grade 1	45·8			42·3		
Percentage Grade 3	28·9			34·6		

N.B.—Multiply crop weights by 8 to convert yields to cwt./acre.

Grades 1 and 2. But the percentage of Grade 3 in the total crop was significantly reduced by spraying (P=0·05).

1954. The season was later than the previous one and sprays were applied by lance, at the same strength and to the same plots as in 1953, on 3rd and 15th June, using 59 and 50 gallons respectively and 200-250 lb. p.s.i. As before, the straw was well soaked at the first application.

The records for the crop, graded as in the previous year, are shown in Table II.

TABLE II.

Mean crop weights for Royal Sovereign in kg. per plot (24 plants) in 1954.

	Sprayed with captan			Unsprayed		
	Grade			Grade		
	1	2	3	1	2	3
Irrigated	5·63	5·35	3·37	3·55	4·06	3·55
Non-irrigated	4·69	5·30	3·35	3·75	4·42	3·03
Mean	5·16	5·32	3·36	3·65	4·24	3·29
Total crop	13·84			11·18		
Marketable crop	10·48 (75·7%)			7·89 (60·6%)		
Percentage Grade 1	37·3			32·6		
Percentage Grade 3	24·3			29·4		

N.B.—Multiply crop weights by 8 to convert yields to cwt./acre.

Analysis of variance shows that spraying with captan gave highly significant increases (P=0·01) in total crop and in marketable crop (Grades 1 and 2) ; and a reduction, of similar significance, in the percentage of rotted fruits in the total crop. Spraying significantly (P=0·05) reduced the percentage of rotted fruits whether on irrigated or non-irrigated plots.

As the same treatments were applied in both years to the same plants, it is legitimate as well as instructive to combine the results (Table III).

Table III.

Sum of mean crop weights for Royal Sovereign in kg. per plot (24 plants) for 1953 and 1954 combined.

	Sprayed with captan			Unsprayed		
	Grade			Grade		
	1	2	3	1	2	3
Irrigated	8·99	7·32	5·58	6·14	5·58	5·99
Non-irrigated	8·16	7·09	5·44	6·74	5·93	5·16
Mean	8·57	7·20	5·51	6·44	5·75	5·58
Total crop	21·28			17·77		
Marketable crop	15·77 (74·1%)			12·19 (68·7%)		
Percentage Grade 1	40·3			36·2		
Percentage Grade 3	25·9			31·4		

N.B.—Multiply crop weights by 8 to convert yields to cwt./acre.

Where captan was applied, the total crop per plot represents a total yield per plant in two years of approximately 2 lb. At the planting distances in this trial, which would provide 9,680 plants per acre, this corresponds to a yield of 8·5 tons per acre, of which the 1954 yield would be 5·5 tons. The corresponding yields for the unsprayed plants were 1·64 lb. per plant and 7·1 tons per acre (4·5 tons in 1954). The marketable crop in 1954 from the sprayed plots was 4·2 tons per acre compared with 3·2 tons from unsprayed plots. Both the total and the marketable crops over the two years differed very highly significantly (P=0·001) in favour of the sprayed plots, and the percentage of rotted fruit was correspondingly reduced by spraying.

DISCUSSION.

It must be emphasized that the spray was very thoroughly applied at a mean rate equivalent to over 700 gallons/acre per application, and that much less would probably be used in commercial practice. Nevertheless, as Powell (1952, 1954) has already pointed out, the chances of infection on small experimental plots which include unsprayed controls are much greater than they would be in a uniformly sprayed area such as a commercial plantation. In the trial reported by Marsh, Martin and Crang (1955), 0·25 per cent. captan at 250-350 gallons/acre, applied three times to the plants only, gave 50-70 per cent. control; captan at 0·125 per cent. was less effective. Thus, on the plants, the dosage/acre was considerably higher than that used here.

In the present trial, irrigation increased the percentage of rotted fruits on the unsprayed plots. Spraying with captan reduced the rotting very much more on the irrigated than on the non-irrigated plots and more than outweighed the adverse effect of irrigation.

In many other experiments irrigation has not increased the incidence of *Botrytis* rot (Wilson, 1954), but evidently, in conditions where this disease is increased by irrigation, as in this trial, the losses of crop could be more than offset by thorough spraying with an efficient fungicide.

SUMMARY.

1. A two-year trial for the control of *Botrytis* rot (Grey Mould) of strawberries by spraying was carried out on irrigated and non-irrigated plots of the variety Royal Sovereign. The fungicide used was captan (N-trichloromethylthiotetrahydrophthalimide) formulated as a 50 per cent. wettable powder. In both years, two post-blossom sprays, at 2 lb./100 gallons and an average rate of over 700 gallons acre, were thoroughly applied by lance to strawed alleys as well as plants.

2. The application of fungicide significantly reduced the percentage of rotted fruit and increased the total and marketable crops, especially on irrigated plots. Spraying with captan increased the marketable crop in the two years by about 30 per cent.

3. In this trial, irrigation by hose increased the losses due to rotting on plots receiving no fungicide, but gave higher yields on fungicide-sprayed plots. Hence, where irrigation is practised, fungicide applications may sometimes be required to obtain maximum advantage.

ACKNOWLEDGMENT.

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THE CONTROL OF *BOTRYTIS* ROT (GREY MOULD) OF STRAWBERRIES, AND THE EFFECTS OF FUNGICIDE SPRAY RESIDUES ON THE PROCESSED FRUIT

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In consultation with East Malling Research Station, preliminary trials of fungicides for use in controlling strawberry fruit infection by *Botrytis cinerea* Pers. *ex* Fr. were made at Long Ashton in 1954, preparatory to the planning of long-term trials on plots of Royal Sovereign at the Experimental Horticulture Station, Luddington. In the absence of suitable plots of Royal Sovereign, the experiments were made on Auchincruive Climax. Of the fungicides chosen, thiram and tecnazene had shown promising field performance against *Botrytis* on other crops and captan had been reported to give satisfactory control of *Botrytis* on strawberries in the U.S.A. (Powell, 1952). Salicylanilide was included as a material considered unobjectionable on ripe fruit.

Fruits from the sprayed plots were canned or made into jam, and the effects of spray residues on flavour and appearance were assessed. An analytical study of the levels of captan on both fresh and processed fruit was made as part of a wider investigation on spray deposits and residues which is being published elsewhere (Martin and Pickard, 1955).

Lay-out.

The trials were made on a plot of Auchincruive Climax in their third cropping year. Many of the plants were virus-infected, causing a mean loss of 25 per cent. in plant vigour (assessed 12th July). The planting distance was 1 ft. 6 in. in rows 3 ft. apart ; every third row had served as a buffer in an inconclusive manurial trial discontinued in 1953. Six of these buffer rows were used for the 1954 spraying trial ; each was divided into three 18-plant units, thus providing for a control and five fungicide treatments, randomized in each of three equal blocks.

Materials and Methods.

Fungicides.

All the fungicides were applied as sprays, brief specifications being :

Captan : 0·5 per cent. of a dispersible powder formulation, i.e. 0·25 per cent. captan (Treatment A).

Captan : 0·25 per cent. of a dispersible powder formulation, i.e. 0·125 per cent. captan (Treatment B).

Tecnazene : 1 per cent. of a 20 per cent. tetrachlornitrobenzene solution in emulsifiable xylene, i.e. 0·2 per cent. tecnazene (Treatment C).

Thiram : 0·5 per cent. of an 80 per cent. dispersible powder formulation, i.e. 0·4 per cent. thiram (Treatment D).

Salicylanilide ; 0·2 per cent. suspended in a 0·75 per cent. sulphite lye solution (Treatment E).

The unsprayed controls constituted Treatment F.

Analytical methods.

The method used for the determination of deposits of captan on the fruits was an adaptation of one proposed by Kittleson (1952) for the examination of tomatoes. The principle of the method is the development of a yellow colour when captan is heated with resorcinol.

When formed in neutral ethyl alcohol solution under the conditions described by Kittleson, the colour was found to be unstable, but this defect was remedied by the use of an acidified alcohol solution. Waxes and pigment removed by the chloroform caused interference in the test, but this was considerably reduced by passing the initial extracts through a column of activated alumina. A full description of the method used has been given elsewhere (Martin and Pickard, 1955) ; the main steps were as follows :

The plant material under examination was washed with successive portions of warm chloroform, the washings combined, concentrated by gentle distillation and made up to volume. Aliquots were passed through a column of 0·5 g. alumina and washed through with more chloroform, the percolate being collected in a boiling tube ; 0·3 g. resorcinol was added and the solvent removed at 45°C. by passing a stream of dry air over its surface. The tube was then kept in an oil bath at 135°C. for 15 minutes, with occasional rotation. After removal from the bath, 10 ml. of 90 per cent. ethyl alcohol (containing 0·05 per cent. by weight sulphuric acid) were added just before solidification occurred. Any wax separating was removed by filtration. The optical density of the colour produced was taken one hour later with the Spekker absorptiometer, a 1 cm. cell and violet filter No. 601. The content of captan was obtained from a standard curve prepared from tests with the pure material. All-glass apparatus was used throughout the method.

Processing methods.

Canning. Samples of fruit from early and late picks of each treatment were canned in sugar syrup and in water. In the earliest pick (July 9th) the ripest sound fruit was selected from about 5 lb., plugged, and 17 oz. packed unrinsed into an A2½ fruit-lacquered can ; the cans were then filled with boiling 40° Brix sugar syrup, sealed and processed in boiling water for 20 to 25 minutes, depending on the time taken for the water to re-boil. This treatment would ensure that the temperature of the contents of the can, even in the coolest part, remained at over 160°F. for approximately 20 minutes, with a peak temperature of about 200°. The cans were cooled in cold, running water. The series canned on July 14th was processed in the same way and a corresponding series was canned in water on July 13th. Two further series of the strawberries were canned in water and in syrup respectively on 23rd July and 26th July.

Jam. Small quantities of jam were made from the ripest fruit left after the canning samples had been taken on 9th July. The quantities used were in the proportion of 7 lb. fruit and 6 lb. sugar boiled to give 10 lb. of jam. The maximum temperature reached in boiling the jam was approximately 220°F. The jam was stored in 1 lb. jars with parchment covers.

Flavour assessment.

The fruit from each can was divided into two lots, placed in identical glass bowls, and coded. Fruits were offered in groups of three, each group including two samples from the same can and one from a different can. The triangular tasting method was used for flavour assessment, the panel of 8-11 tasters being asked to note, if possible, the two similar samples in each group of three, and also to indicate the samples having any taint.

The jams were coded, and the members of the tasting panel were asked to note those with any taint.

Field Records.

Spray applications.

All the sprays were prepared without difficulty and gave stable suspensions. Spraying was done by hand, with a self-supplying continuous-delivery syringe fitted with an extension rod and nozzle to obviate spray drift. The applications were made in calm, dry weather as follows :

First application : 17th May. On this date the first quarter of the blossoms were open. Approximately 1½ gal. of diluted spray was applied for each treatment (54 plants), equivalent to 250 gal. per acre.

Second application : 1st June. This closely followed the period of peak blossoming. The quantities applied were as on 17th May.

Third application : 29th June. At this date most of the fruits were changing from green to pale pink, but a few early berries were almost ripe. The volume applied was 2-2½ gal. per 54 plants.

After each spraying an obvious deposit was present on the leaves and fruit sprayed with 0·25 per cent. captan, and a lighter deposit on those sprayed with 0·125 per cent. captan or 0·4 per cent. thiram. No deposit was seen on the salicylanilide or tecnazene plots. These residues were visible up to 16th July but were not seen on 24th July. No spray damage was caused by any of the treatments.

Weather.

As indicated by the blossoming dates, 1954 was a late season for the strawberry crop. After a drought period (5th-30th April), the first week of May was wet, another dry period continued until 20th May, followed by showery weather from the 21st to 29th. The total May rainfall was 2·21 in. (normal 2·59) ; sunshine was 4·72 hr. per day (normal 6·3).

From 29th May to 4th June the weather was dry, but in the period 5th-12th June 3·91 in. of rain fell. Total June rainfall was 4·29 in. (normal 2·11) and sunshine 5·08 hr. per day (normal 7·09).

The principal wet periods in July were 13th-17th (1·34 in.) and 23rd-28th (2·08 in.). The July total was 4·05 in. (normal 3·16) and sunshine per day 3·95 (normal 6·0).

Night temperatures in June and July were unusually low, the ground readings being 40°F. or below on nine nights in June and three in July. A ground frost (31°F.) was recorded on the night of 7th July.

The persistently cool, sunless weather delayed ripening, and the process of picking was often hampered by rain.

Disease incidence.

Wet periods and slow drying encouraged *Botrytis* attack, which was first noted at the end of June, spreading from infected sepals to the fruit. The attack became epidemic after the wet period of 13th-17th July, and by the end of July the disease was affecting more than half the crop on the control plots. Little infection of fruit by other fungi (e.g. *Sphaerotheca humuli*) was noted.

RESULTS.

Yields and disease control.

Seven picks were made on the experimental plots, the picking dates being 9th, 13th, 14th, 16th, 19th, 24th and 27th July. At each date all the fully-ripe and diseased berries were picked, weighed, counted, and removed from the plot. The results are shown in Fig. 1, which is based on the mean numbers of *Botrytis*-attacked berries per lb. of sound fruit.

The overall crop totals associated with the different treatments were : captan 0·25 per cent., 78 lb. 7 oz. ; captan 0·125 per cent., 63 lb. 7 oz. ; salicylanilide 66 lb. 14 oz. ; tecnazene 61 lb. 6 oz. ; thiram 75 lb. 15 oz. ; unsprayed 58 lb. 1 oz. Differences over 17 lb. 1 oz. are significant at P=0·05, i.e. the captan 0·25 per cent. plots out-yielded the unsprayed and the tecnazene-treated plots ; the thiram-treated plots out-yielded the unsprayed. Because, however, of the erratic distribution of virus-weakened plants in this trial the plot yield differences could not be attributed solely to the spray treatments.

The disease control records are assembled in Table I.

TABLE I.

Mean number of Botrytis-*attacked berries per lb. of sound fruit.*

	Picking date						
	July 9th	13th	14th	16th	19th	24th	27th
A. Captan 0·25% ..	0·3	0	1·3	0·4	1·2	11·5	13·2
D. Thiram	0·2	0	0·2	0·1	1·1	11·2	15·2
B. Captan 0·125% ..	0·7	0	0·7	0·8	1·1	20·0	30·0
C. Tecnazene	0·6	0·8	1·9	1·2	3·8	37·8	40·3
E. Salicylanilide	1·5	0·4	3·7	2·1	3·1	41·4	66·8
F. Control	1·6	2·3	5·4	2·6	3·0	30·3	40·4

Table I shows that the tecnazene and salicylanilide sprays were ineffective throughout, and that in the period of relatively light infection up to 19th July, the two captan sprays and thiram gave approximately equal control. After 19th July, when the *Botrytis* attack became epidemic, the 0·125 per cent. captan spray was inferior to the 0·25 per cent. captan. The latter was approximately equal in fungicidal performance to 0·4 per cent. thiram ; each reduced the *Botrytis* attack to about one-third of that in the control, tecnazene and salicylanilide plots. (See Fig. 1.)

Residues on fresh fruit.

Berries from the picks up to 16th July showed a faint whitish deposit of fungicide residues from the thiram and 0·25 per cent. captan treatments. This deposit was

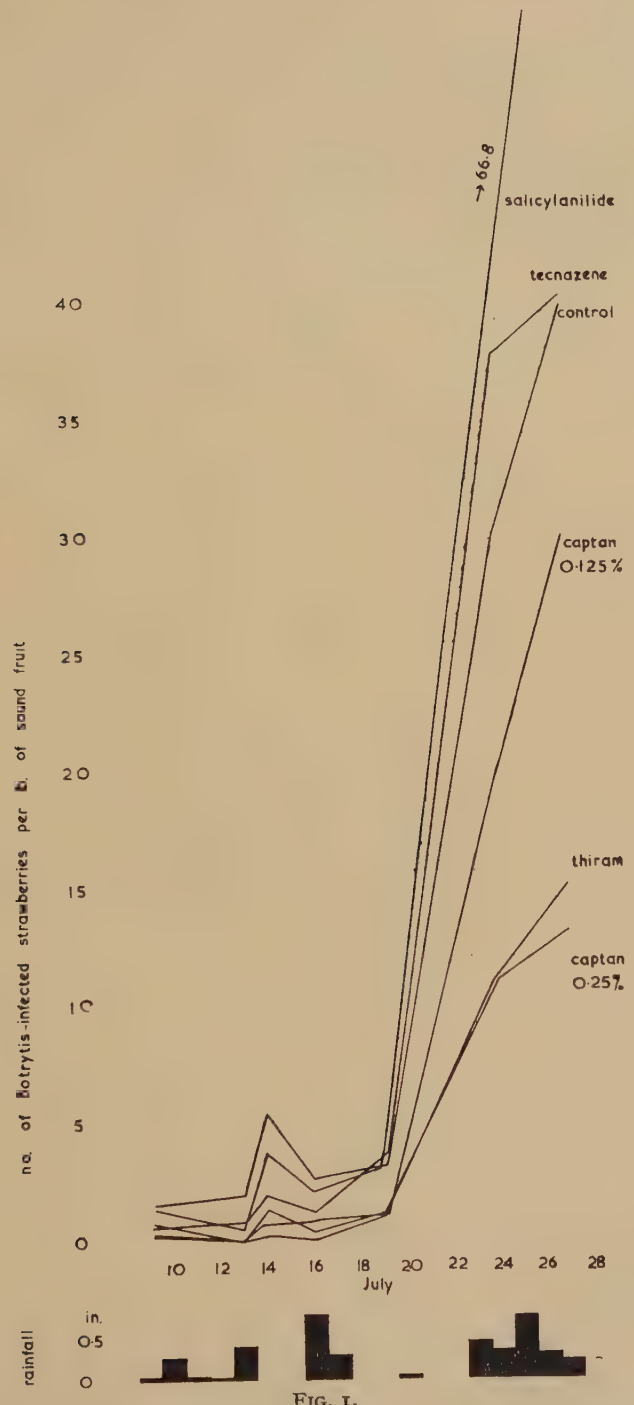

Fig. 1.

Development of *Botrytis* attack in relation to fungicide treatments.

not sufficient to depreciate the commercial value of the fruit. The taste of the fresh fruits was not affected by any of the spray treatments, and an assay of their ascorbic-acid content showed no significant differences.*

Analytical data for captan on fresh fruit, calyces and foliage.

Determinations were made of the levels of captan deposits on the fruits of sprayed and unsprayed plants, samples being taken on 7th, 14th and 18th July. To obtain a measure of the captan present on the surface of the fruits, the calyces were cut off before analysis. The results are shown in Table II.

TABLE II.

Captan spray residues (expressed as p.p.m. captan) on fresh fruits.

Date	Treatment		
	Unsprayed	Sprayed	
		0·125% captan	0·25% captan
7th July	0·6	13	17
	0·4	13	19
14th July	1·0	8	13
	0·9	9	11
18th July	0·4	8	18
	0·8	7	16

The average weight of the fruits analysed on 7th July was 11 g. At the level of 18 p.p.m., each fruit therefore held a deposit of 0·2 mg. captan.

Analyses were also carried out on the 7th July on the foliage of sprayed and unsprayed plants and on the calyces removed from the fruits. The deposits on the fresh leaves were of the order of 500 p.p.m. and on the calyces 800 p.p.m. after the three applications of captan at 0·25 per cent., the high values resulting from the large surface area of leafy tissues in relation to their weight. High levels of residues were again recorded on the 18th July.

The results showed that captan persisted well on fruits and foliage under the adverse weather conditions during the experiment.

Residues on fruit canned in water, on fruit canned in syrup, and in jam.

Attempts were made to determine the levels of contamination of the processed fruits. With the canned fruits, the solid and liquid portions were analysed separately. Continuous percolation with chloroform was carried out for 32 hours, and the method of analysis continued as before. Captan was not found in any of the materials. This was not due to failure to extract, since captan, added to the syrups or jam, could be detected although the recovery was not complete.

Effects of spray residues on processed fruit.

Samples of the canned fruit and the jam were assessed for flavour on five dates in November, by the method described earlier. Fruits from the plots treated with

* An assay made on July 12th gave the following figures for mg. ascorbic acid per 100 g. fresh fruit : Treatment A, 62·3 ; B, 65·4 ; C, 60·9 ; D, 59·8 ; E, 60·9 ; F, 59·2 (accurate to ±5%).

either salicylanilide or tecnazene and canned in water or in syrup showed no significant difference in flavour, aroma or appearance from the unsprayed controls. The results for the thiram- and captan-sprayed fruit are assembled in Table III. It will be noted that tainting was recorded for thiram and both strengths of captan. Tainting resulting from 0·125 per cent. captan was not significantly different from that induced by 0·25 per cent. captan, but the adverse effect of the captan residues was throughout much less than that of thiram at 0·4 per cent. The cans of thiram-treated strawberries had an unpleasant aroma when freshly opened. None of the treatments had any obvious effect on the appearance or texture of the canned fruit.

The jams made from the treated fruit on 9th July were assessed by a panel of nine tasters on 27th November; no adverse effect of any of the treatments was recorded.

Table III.

Results of tasting-panel tests on canned strawberries :

Picking and canning date	Fluid contents	Tasting date	No. of tasters	No. of cans	Tasters finding taint in both cans	Tasters finding taint in one can	Tasters finding no taint
(i) *from plots sprayed three times with 0·4 per cent. thiram.*							
9th July ..	Syrup	23rd Nov.	9	2	8	1	0
13th July ..	Water	10th Nov.	8	1	—	7	1
14th July ..	Syrup	29th Nov.	9	2	9	0	0
23rd July ..	Water	23rd Nov.	10	2	7	2	1
26th July ..	Syrup	29th Nov.	11	2	5	3*	3
(ii) *from plots sprayed three times with 0·25 per cent. captan.*							
9th July ..	Syrup	23rd Nov.	9	2	1*	3*	5
13th July ..	Water	10th Nov.	8	2	0	1*	7
13th July ..	Water	30th Nov.	10	2	5	2*	3
14th July ..	Syrup	29th Nov.	9	2	3*	0	6
23rd July ..	Water	23rd Nov.	10	2	2	2*	6
26th July ..	Syrup	29th Nov.	11	2	2*	0	9
(iii) *from plots sprayed three times with 0·125 per cent. captan.*							
9th July ..	Syrup	23rd Nov.	9	1	—	5*	4
13th July ..	Water	30th Nov.	10	2	2	2	6
14th July ..	Syrup	29th Nov.	9	1	—	3	6
23rd July ..	Water	23rd Nov.	10	1	—	3*	7
26th July ..	Syrup	29th Nov.	11	1	—	0	11

* Taint recorded as slight.

DISCUSSION.

The results obtained in the field trial agree with those from East Malling (Kirby *et al.*, 1955; Moore and Tew, 1955) in showing the value of both captan and thiram in checking a heavy attack by *Botrytis* on ripening strawberry fruits.

In 1954 the ripening period of strawberries was protracted, because of the prevalence of cool, sunless weather in May and June. As a result, the three applications bridging the period between first blossoming and first picking were spaced over

6 weeks—in a normal season this period would be approximately 4 weeks. Further, it was not practicable to test a range of strengths of fungicides and times of application in this preliminary trial. More extensive field experiments both on strengths of materials and times of spraying are therefore necessary before a programme of *Botrytis* control on strawberries can be drawn up for general recommendation.

A major factor to be considered in formulating a programme of sprays for application to ripening fruit is the tenacity of the spray residue. In the trials described in this paper no retention figures are available for thiram, but the analytical results for captan spray deposits indicate a high degree of persistence on the fresh fruit in a period of heavy rainfall.

While such persistence is advantageous in preventing *Botrytis* infection it may be objectionable to the consumer of the fruit. In the present trials it did not appear that any of the fungicide residues on the fresh fruit was sufficiently obvious to reduce the attractiveness of the sample ; neither did these residues affect flavour or vitamin content of the unprocessed berries.

The processing trials established the absence of deleterious effects when any of the sprayed fruits were made into jam. Canned strawberries from the thiram-sprayed plots were, however, strongly tainted, even when the fruits were picked 24 days after the final spraying. A less noticeable but significant tainting was recorded in canned strawberries from the captan-sprayed plots. Tainting of canned thiram-sprayed fruits has been previously recorded for blackcurrants (Adam, Dickinson and Marsh, 1946) but no reference to taint resulting from captan spraying has been found. The chemical tests failed to show the presence of captan in the canned fruits, so that the tainting observed was probably caused by a decomposition product as yet unidentified.

SUMMARY.

In a preliminary field trial on Auchincruive Climax strawberries, three sprays, applied during the period from blossom to harvest, of 0·25 per cent. captan or of 0·4 per cent. thiram, reduced *Botrytis* rot on the berries to approximately one-third of the level on the corresponding unsprayed plots. Captan at 0·125 per cent. was less efficacious ; 0·2 per cent. tecnazene and 0·2 per cent. salicylanilide sprays gave no control of the disease.

The maximum level of captan residue recorded on the ripe strawberries was 19 p.p.m. This deposit did not affect the flavour or the ascorbic-acid content of the fresh fruit.

In processing trials, canned strawberries from thiram-sprayed plots developed marked tainting. There was a less noticeable tainting in the canned fruit from plots sprayed with captan. This tainting was apparently caused by a decomposition product of the fungicide, since no captan could be detected in the canned fruit.

No deleterious effect was noted in jams made from any of the sprayed fruits.

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THE INCEPTION OF FLOWERING IN SOME APPLE ROOTSTOCK VARIETIES

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THE young apple tree, before it comes to flower, repeats only the pattern of growth it has already established—new shoots, secondary thickening and new roots. When it comes into bearing, flowers, fruits and seeds constitute additional end points of development, and the tree's metabolism is no longer wholly involved in the cycle of its own enlargement. Thus the inception of flowering, i.e. the coming into flower for the first time in the plant's life, is an important stage in the development of the tree, marking the onset both of economic returns and of a drain on the growth activities of the tree. Although much work is being done on the physiology of flowering (reviewed by Lang, 1952) this is mostly concerned with annuals and biennials, whereas apple trees on their own roots do not flower until about ten years from germination (Tydeman, 1928). A further difference is that fruit trees normally consist of scion varieties, which have once formed part of fruiting trees worked on to a rootstock ; their failure to flower in the earliest years after budding indicates a " mature " as contrasted with a " juvenile " or seedling condition of non-flowering.

The present paper deals with the inception of flowering in an experiment on rootstock and scion influence on growth by Vyvyan and Maggs (1954). The experimental treatments were the sixteen possible combinations of four apple rootstock varieties worked together in pairs, and the effect of budding was estimated by including the unworked varieties. The varieties were the apple rootstocks, M.II, M.IV, M.IX and M.XVI (*Malus pumila*, Mill.), so that the treatments were M.II, M.II/M.II (M.II budded on to M.II), M.IV/M.II, M.IX/M.II, M.XVI M.II, and so on with the remaining three rootstocks. Trees budded with the same clone are called " self-budded " (e.g. M.II/M.II), while those budded with a different clone are called " cross-budded " (e.g. (M.II/M.IV). Rootstock varieties were used in the experiment as the same varieties were required both as scions and as rootstocks, and with the varieties chosen a wide range of vigour could be expected with some confidence (Hatton, 1935). At one extreme, M.IX grows slowly and, as a rootstock, is very dwarfing and induces prolific flowering within one or two years ; at the other extreme, M.XVI is very vigorous and trees with this rootstock do not reach full cropping for about 15 years. M.II is intermediate between these last two, while trees worked on M.IV grow quite vigorously for about 10 years and then slow down, possibly because of the heavy crops they have borne. In this experiment, however, the various combinations of M.XVI were slightly smaller 3 years after budding than the corresponding ones on M.II ; on the other hand, M.XVI has markedly kept down the production of flowers.

The rootstocks were planted in 1950 in six randomized blocks with 26 trees per plot, and the trees were budded the same year. In 1952 any maidens flowering were deblossomed. In 1953 an experiment to measure the effect of blossoming and fruiting on subsequent growth was superimposed, and thereafter certain trees have been regularly deblossomed each spring. At intervals, trees have been dug and

analysed into growth fractions ; consequently, the number of trees left in the field is diminishing, and after 1954 there were insufficient trees for the data to be treated by the methods used in this paper. By the third spring after budding (1953), there were 48 trees left in each treatment and in 1954 there were 30, of which 12 had been deblossomed where necessary and 18 allowed to flower. At a suitable time the flower trusses on all trees were counted. Trees worked with M.XVI scions flowered several weeks later than the others, but there were no rootstock effects large enough to make more than these two observation occasions necessary.

Proportion of Trees Flowering.

In 1952, two years after budding, 9 maiden trees out of 2,160 flowered (0·4 per cent.) ; of these 7 were IX/IX and 2 were, surprisingly, IV/II. In 1953, 31 per cent., and in 1954, 48 per cent. of the trees flowered. The treatment averages for each year are represented in Fig. 1, and the average percentages for scion and rootstock effect

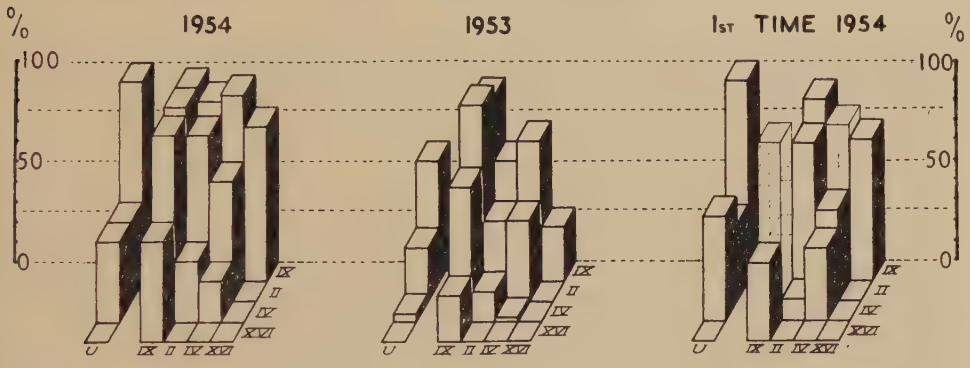

Fig. 1.

Percentage of trees flowering, arranged according to rootstock (front to back) and scion (horizontally). The data for 1954, 1953 and for the trees flowering for the first time in 1954 are represented separately. At the left of each group are the unbudded trees (U). These should be compared with the self-budded trees. The faint columns in the right hand diagram (1st time 1954) are for values based on less than 10 trees.

are given in Table I. In the figure, the varieties have been arranged so that the rootstock which induces maximum per cent. flowering is at the back ; scion varieties are similarly arranged from left to right, while the unworked trees are represented as detached at the left of each diagram. The values for trees which flowered for the first time in 1954 are also shown. The following points are of interest :

1. The general similarity in behaviour of a variety as a scion and as a rootstock, as shown by the Rootstock and Scion Effects of Table I and by the performance of each variety depicted in Fig. 1.

2. The earlier onset of flowering among budded trees as shown by the greater number of budded than of unbudded trees flowering in 1953.

3. The non-uniformity in flowering behaviour within a treatment. Thus, in only one treatment (unbudded M.IX) did all the trees flower in two years, and as Fig. 1 shows, trees flowering for the first time in 1954 are distributed in a pattern very similar to that for all trees, suggesting that treatments with low initial flowering would

TABLE I.

Percentage trees flowering—main effects for rootstock and scion.

	Variety					Year
	M.II	M.IV	M.IX	M.XVI	Average	
Rootstock effect ..	44	21	62	6	} 33	1953
Scion effect	29	28	69	7		
Rootstock effect ..	60	36	89	13	} 48	1954
Scion effect	48	41	84	19		

Unbudded	Self-budded	Cross-budded	
23	33	33	1953
45	53	48	1954

not reach 100 per cent. flowering for some years. This variability is not due to the size differences usually attributed to variations of soil and other conditions, since flowering and non-flowering groups include both large and small individuals, and of two adjacent trees equal in size, one may be in flower and the other not.

NUMBER OF INFLORESCENCES PER TREE.

Even within treatments, the number of inflorescences borne by a tree was very variable, having a residual standard error of 6·9 in 1953 and 21·2 in 1954, while the general means were 4·0 and 15·3 respectively. Despite this, as the values in Tables II and III show, the effects of scion and rootstock variety were well marked. The most striking point is the general similarity in varietal effect to that recorded for percentage flowering. This similarity extends to comparisons between cross-budded, self-budded and unbudded categories. The high value for cross-budded trees in 1954 (Table II) is mostly due to the large number of inflorescences on the M.IX/M.II trees (80·8 per tree). The treatments involving M.XVI have been omitted from the calculations summarized in the lower part of Tables II and IV because so many of them bore no flowers at all.

TABLE II.

Average number of inflorescences per tree—main effects for rootstock and scion.

	Variety					Year
	M.II	M.IV	M.IX	M.XVI	Average	
Rootstock effect ..	7·1	1·5	8·9	0·2	} 4·0	1953
Scion effect	1·9	2·9	12·7	0·2		
Rootstock effect ..	24·8	7·7	28·9	0·9	} 15·3	1954
Scion effect	5·2	16·5	38·8	1·7		

Unbudded	Self-budded (*Treatments involving M.XVI omitted*)	Cross-budded	
3·3	7·5	7·8	1953
18·8	17·0	31·3	1954

Table III.

Average number of inflorescences per tree, 1954.

Rootstock	Scion				
	Unbudded	M.II	M.IV	M.IX	M.XVI
M.II	1·8	4·9	13·4	80·8	0
M.IV	1·7	0·2	2·9	27·5	0
M.IX	53·0	15·8	49·8	43·1	6·8
M.XVI	0	0	0	3·6	0

As the number of trusses that a tree can carry is influenced by size as well as by inherent fertility, the average numbers of inflorescences per kilogramme dry weight of tree are given in Table IV. The effect of this transformation is to emphasize the

Table IV.

Average number of inflorescences per kilogramme dry weight.

	Variety					Year
	M.II	M.IV	M.IX	M.XVI	Average	
Rootstock effect ..	21·4	6·5	54·4	0·8	} 20·8	1953
Scion effect	8·2	16·9	56·9	1·1		
Rootstock effect ..	31·8	10·5	77·0	1·7	} 30·2	1954
Scion effect	11·5	32·7	72·1	4·7		

Unbudded	Self-budded (*Treatments involving M.XVI omitted*)	Cross-budded	
15·5	43·0	32·7	1953
51·0	49·1	51·8	1954

high fertility of the M.IX combinations, previously masked by the smallness of the trees. The large numbers of inflorescences on the M.IX/M.II trees are largely a result of greater tree size and, on the basis of equal weights, it appears that self- and cross-budded trees are of equal fertility. The numbers of inflorescences per kilogramme of 1-year-old wood were also calculated ; the values closely parallel those of Table IV and so are not given.

Relation between proportion of trees flowering and number of inflorescences per tree.

The general parallelism between the proportion of trees flowering and mean number of inflorescences per tree has already been noted. If a precise relation were established it would imply that :

1. The cause initiating flowering also operated in the subsequent production of flowers.
2. The cause was effective within the plant at the same rate (or a related rate) as among members of the same treatment.

These conditions become the same either if the individuals of a clone are regarded as still behaving as part of a single individual or if the site of action of the cause is the individual bud rather than the whole plant. In both, flowering sets in at rates which are related between and within plants. To test this, the average number of trusses per tree in each treatment was plotted against the percentage of trees flowering. The points thus obtained lay about a definite curve, in which it was clear that a good deal of the scatter was due to a small proportion of the trees having very many trusses. To reduce this scatter the averages of the summed logarithms of the number of inflorescences were calculated. As log 0 is minus infinity, 0·4 was added to the number of trusses on each tree, so that non-flowering trees were scored as log 0·4, etc. This produced the smooth curve given in Fig. 2. There is clearly a definite relation between the two variables. This curve is not an artefact resulting from the logarithmic scaling down for, if all treatments tended to have the same

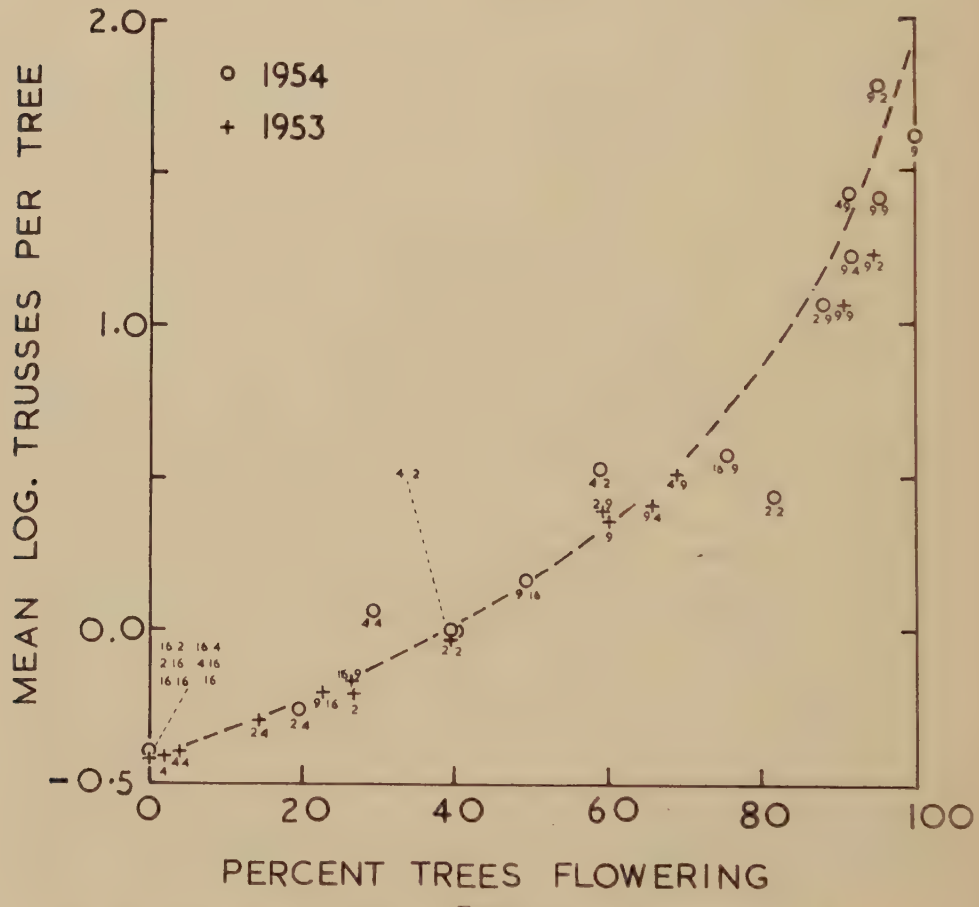

Fig. 2.

The relation between the percentage of trees flowering in each treatment and the mean log. number of trusses per tree (log. geometric mean). The suffixes to each symbol indicate the rootstock-scion combination represented ; thus "9 16" stands for M.IX/M.XVI, etc.

mean number of trusses per flowering tree, the result would be a straight line. To check the generality of the relation, other data on the inception of flowering in apples were examined and, although they were much less extensive than in the present experiment, similar curves were obtained.

The curvature of the line on this scale implies that, as more trees come to flower, the number of inflorescences per tree increases at an even greater rate, whence it may be inferred that the production of flowers requires much less stringent conditions than the establishment of the capacity to flower ; or that if one bud is able to initiate flower primordia the chances are that other buds on the tree will do so as well, to an extent *characteristic of the treatment.* This is compatible with the view that, in the apple, flowering is controlled by the attainment of a critical value of the causal factor in the individual bud ; so that, within the individual tree, if any one bud has nearly attained that value, it is likely that others will have done so too, their actual numbers being determined by the treatment.

Within the treatment the proportion of trees flowering is related to the mean rate at which the causal factor achieves its critical value, this rate differing from treatment to treatment. Although this mechanism would account for the relation shown between per cent. flowering and average number of trusses, it does not indicate why one tree may be in full bloom, yet its neighbour in the same plot is without a single blossom ; it merely indicates how many of each kind are to be expected.

Practical applications of the relation may be found in those investigations where it is necessary to estimate the effects of various treatments on flower production ; instead of counting the number of trusses on each tree, the number of trees flowering in each treatment may be counted, provided enough are (closely) planted. This will give relative fertilities ; absolute values may be estimated by counting the trusses on sufficient treatments to establish the shape of the curve.

Effect of the previous year's blossom and of deblossoming.

The number of flower trusses borne by a tree in 1954 might have been influenced by the number borne in 1953 ; moreover, some of the trees had been deblossomed in 1953. The influence of these factors was negligible in 1953 owing to the very low level of flowering in 1952. The records for 1953 and 1954 were therefore examined to determine the effects of these factors.

The effect of deblossoming was similar for all treatments where flowering occurred ; deblossomed trees usually carried more trusses (mean, 28·4) than trees allowed to flower and fruit (mean, 17·8) ($P < 0{\cdot}001$).

Two main sequences could be distinguished in the effect of the amount of blossom in 1953 on that in 1954. Some trees had flowered very profusely in 1953 and initiated a biennial rhythm ; these usually bore little blossom in 1954 ; as might be expected, some M.IX combinations were prone to do this. Where this behaviour was general throughout a treatment, 1954 blossoming might be expected to vary inversely with 1953 blossoming. Some trends this way were found (M.IX, M.IX/M.IX M.IV/M.IX). On the other hand, vigorous trees which flowered lightly in 1953 often both grew strongly and flowered more heavily in 1954. In such instances 1953 and 1954 flowering would be expected to vary together and this did in fact occur. However, because of the small number of trees in each treatment and because of the range in behaviour possible, it cannot be stated with confidence that any particular treatment predominantly followed one sequence or the other.

There was also a tendency for deblossoming to reverse the trend of each sequence ; thus trees flowering heavily would, after deblossoming, grow and blossom more profusely the following year (in agreement with Singh, 1948), whereas sparsely flowering trees would lose, after deblossoming; even the slight check their crop might provide, and so tend to remain sparsely flowering in the following year. Thus when the regression of flowering in 1954 on that in 1953 was examined for the deblossomed and fruiting trees separately, it was significant and positive for the fruiting trees, but not for the deblossomed trees. The significance was due to the preponderance of treatments showing the direct sequence described earlier, while only a few showed the inverse sequence of biennial bearing.

If there is a direct relation between the amount of blossom one year and the next the implications are interesting. The causes may be edaphic—but limited to the differences between adjacent square yards of land—or the clones may have differentiated into strains of differing flowering capacity. There is no direct selection for flowering capacity in a stoolbed and therefore light and heavy flowering strains may have persisted equally.

Position of the trusses.

In 1953, flower trusses were classified as " axillary ", " terminal on a shoot " or "terminal on a spur", a spur being taken as a shoot of the previous year less than 5 cm. long (Vyvyan and Evans, 1932). Deductions from the results were somewhat spoilt because some shoot tips were killed back before flowering by an unidentified disease to which M.II and M.IV seemed to be more susceptible than M.IX and M.XVI. However, when the number of axillary trusses was expressed as a proportion of total inflorescences, the results suggested that, both as rootstock and as scion, M.II produced more axillary than terminal trusses, with the reverse characterizing M.IV ; M.IX was intermediate ; there were insufficient data for M.XVI.

The position of trusses along the leader was also recorded in the hope that a pattern might be found underlying the apparently random runs of fertile and vegetative buds along the shoot ; but whether tip or base was taken as the reference point, or proportion of shoot above or below the fertile zone, no such pattern was obtained. Possibly some resolution might have been obtained had the date of unfolding of leaves in the previous year been recorded, so that trusses could have been compared according to their date of formation.

SUMMARY.

1. The inception of flowering was followed in an experiment consisting of the apple rootstock varieties M.II, M.IV, M.IX and M.XVI, both unbudded and budded together in all 16 possible pairs of combinations.

2. When the trees came into flowering for the first time, rootstock and scion variety influenced both the proportion of trees flowering and the number of inflorescences per tree. The varietal influence was similar whether the variety was used as a rootstock or as a scion. The order of decreasing flower production was M.IX, M.II, M.IV, M.XVI.

3. More of the budded trees flowered than of the unbudded and they carried more inflorescences.

4. There was, in any given treatment, a definite relation between the proportion of trees flowering and the mean number of inflorescences per tree.

5. Trees allowed to flower and fruit bore fewer inflorescences per tree in the following year than trees deblossomed after flowering.

6. The effects of the previous year's blossom on flowering in the current year were complex. Two sequences were detected :

(i.) An inverse relation (biennial bearing effect).

(ii.) A direct relation.

Deblossoming tended to reverse the trend of each sequence.

7. No regularities could be found underlying the positions of the axillary inflorescences along the terminal shoot (leader).

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PROPAGATION OF PLANTS BY ROOT CUTTINGS

II. SEASONAL FLUCTUATION OF CAPACITY TO REGENERATE FROM ROOTS

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SYNOPSIS

Some species regenerate readily from root cuttings at any time of year, whereas cuttings of other species show a well-marked seasonal fluctuation in capacity to grow. In the latter a high proportion of successes is possible only if cuttings are taken in the " on " season. In the " off " season for raspberry, not only do root cuttings fail but whole root systems, severed and left undisturbed *in situ*, also die. The regenerative capacity of (*a*) root cuttings, and (*b*) severed roots left *in situ*, has a bearing on the degree of control, which can be obtained by tillage, of weed species which are able to regenerate from roots left in the ground.

Earlier work (Hudson, 1954) has shown that some varieties of raspberry (*Rubus idaeus*, L.) can readily be propagated from root cuttings, provided they are made at the right time of year. The capacity of cuttings to grow follows a strongly seasonal cycle, with a short but well-defined " off " season in summer, and a long " on " season from autumn to early spring. In continuation of the work, which was part of an extended study of the factors affecting regeneration from roots,* experiments were carried out to ascertain whether root cuttings of other species showed any seasonal periodicity in their capacity to grow. The effect of removing all shoots from raspberry root systems in the " off " season, but leaving the roots undisturbed *in situ*, was also investigated, to find out whether the incapacity of cuttings to regenerate in the summer months was due to the smallness of their size or to disturbance of their assimilating roots.

Experiments with root cuttings of different species.

In many experiments with raspberries, cuttings of various sizes have been used, from all parts of the roots of plants up to two years old, and grown in a variety of environments, at all seasons of the year. Results have shown that almost any piece of secondarily thickened root more than two or three centimetres long is capable of growing during the " on " season, whereas at other times all cuttings fail, irrespective of their size or the environment into which they are put. It can therefore be concluded that, for raspberries up to two years old, capacity to regenerate at any particular time applies equally to all parts of the thickened root system.

However, despite their inherent capacity to grow in the " on " season, cuttings put in an unsuitable environment may not produce a high proportion of successes, and it was decided that the capacity of species to regenerate from roots could only be ascertained by propagating cuttings in different environments, as well as at various seasons of the year. By using a wide variety of environments it was hoped that, at

* The term " regeneration " has been used in many senses (*vide* McCallum, 1905 ; and McVeigh, 1937, who described no less than six different usages). In the present series of papers the term is used in the broadest sense, to include any cases where the growth of buds from roots may lead ultimately to the development of new plants.

each date of propagation, at least one of them would approach the optimal so that cuttings could achieve (or approach) their theoretical maximum capacity to regenerate.

Batches of cuttings of several different species have therefore been made at regular intervals over a period of a year and groups of 24 cuttings from each batch inserted in each of several environments. These were: (A) a heated glasshouse kept at moderate temperatures with a minimum of about 13°C. ; (B) a cold frame, covered by Dutch lights and normally closed except in hot weather ; (C) and (D) out-of-doors in full sun ; and (E)–(G) three temperature-controlled growth rooms, illuminated by fluorescent daylight tubes giving about 120 f.c. at the soil surface, and operated so as to give day-lengths appropriate to the latitude and season. The chambers were kept at approximately constant temperatures of 21° C. (E), 15·5°C. (F) and 10°C. (G), all controlled to within about ± 1°C. Cuttings were made 10 cm. long for raspberry and 5 cm. for all other species and were inserted horizontally, 1-2 cm. deep in boxes of John Innes Potting Compost No. 1, except that group (D) was planted 3-5 cm. deep in soil in the open ground.

It sometimes happened that cuttings produced strong new shoots but failed to make new roots and ultimately died. Most of the shoots produced from raspberry roots can be propagated as cuttings if they are severed from the roots soon after emerging above ground and put into a suitable environment, and there are indications that this probably holds for many other species. Thus production of a shoot probably indicates a capacity for regeneration even though the shoot may ultimately die if left on the root cutting. The criterion of " success " has therefore been the number of cuttings which made new plants (shoots+roots) plus those which produced shoots but subsequently died, i.e. all cuttings from which at least one new shoot grew.

Some of the most interesting results are summarized below, giving examples of (*a*) fleshy-rooted herbaceous perennials—horseradish, dandelion and dock, (*b*) thinner-rooted herbaceous perennials—phlox and ragwort, (*c*) woody roots bearing buds—raspberry and (*d*) woody roots not bearing visible buds—black poplar.

Horseradish (*Cochlearia armoracia* L.).
Dandelion (*Taraxacum officinale* Weber).

These species regenerated strongly from cuttings of a wide range of sizes at all times of year and under all the environmental conditions tried (Fig. 1, A and B), although certain aspects of growth (e.g. average number of new shoots produced per cutting) were affected by environment.

Raspberry (*Rubus idaeus* L.).

As in previous experiments, cuttings of Lloyd George and Malling Promise raspberries showed a strong seasonal fluctuation in capacity to regenerate (Fig. 1, C and D).

Black poplar (*Populus nigra* L.).

Although a full year's work was not completed, poplar showed a seasonal variation in capacity to regenerate from root cuttings, as in raspberry, with an " off " season in the summer and " on " season in winter. This species differs from raspberry in having roots that do not normally bear visible buds (Fig. 1, E).

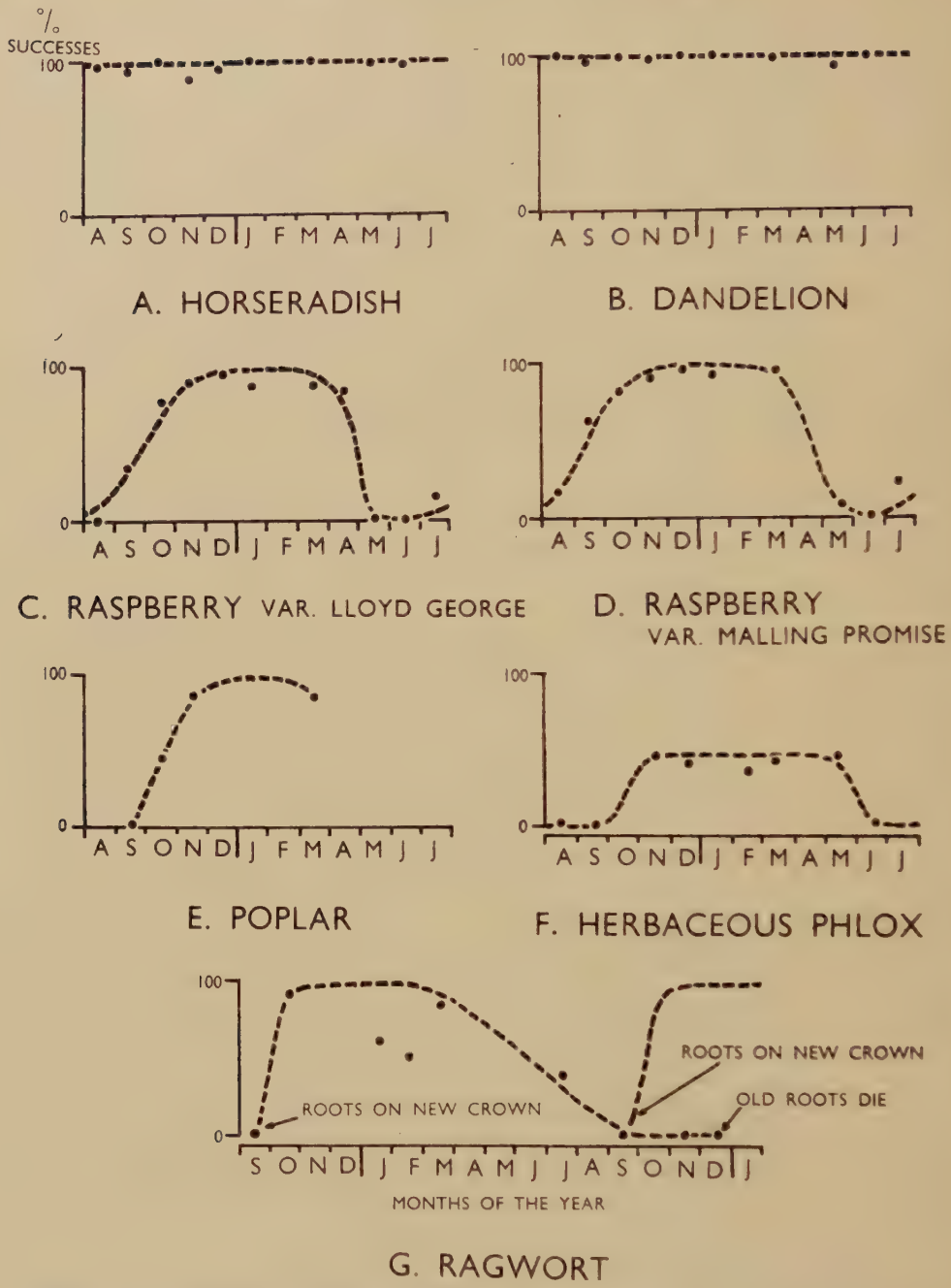

FIG. 1.

Capacity of root cuttings to produce new shoots. Each dot represents the average percentage of cuttings producing new shoots in all the environments (usually six, with 24 cuttings in each) used in that month. The broken curves suggest the probable seasonal pattern of capacity of cuttings to grow. The series for poplar is incomplete.

Ragwort (*Senecio jacobaea* L.).

A strongly seasonal fluctuation in capacity to regenerate was shown, apparently connected with the age of the particular root from which the cutting was made. The life cycle of each root is shorter than in woody species such as raspberry and poplar. Roots arising from the current season's crown will regenerate at a time when roots from the previous season's crown will not (Fig. 1, G).

Herbaceous phlox (vars. of *Phlox paniculata* L.).

Capacity to regenerate from root cuttings showed a strongly seasonal cycle, though a rather low percentage of cuttings grew even in the " on " season (Fig. 1, F.).

Dock (*Rumex obtusifolius* L.).

Root cuttings of dock showed almost no capacity to regenerate, although pieces of stem taken from just below ground level often grew, producing shoots from pre-existing buds. In two different years, a very small proportion of the true root cuttings of dock made in March regenerated but none at other times, although cuttings often remained alive in the soil for more than a year. Further work is proceeding on this species.

Regeneration of raspberry roots severed *in situ*.

Experimental method.

In the management of a raspberry cane nursery (as described by Wood, 1949, and others) the whole area is cleared of aerial growth each winter by digging out all root suckers. Roots which remain in the ground produce a prolific crop of new suckers in the following spring, showing that raspberry roots isolated in the winter (the " on " season for root cuttings) can regenerate if left *in situ*. Entire raspberry roots were isolated in spring and summer to study their behaviour in the " off " season for root cuttings.

An observation bearing on this question had earlier been made when all the aerial shoots on a well-established two-year-old bed of Malling Promise, 22 feet by 10 feet, had been cut off at ground level on 6th June, 1951. The bed contained several hundreds of strongly growing canes but, despite the vigour of the plants, no new shoots appeared above ground after cutting and when the area was dug in the autumn it was found that all roots were dead.

To investigate this question further young raspberry plants of the varieties Lloyd George and Malling Promise were planted in the open ground in May 1952 at a spacing of six feet apart each way and allowed to grow undisturbed for a season in order to produce well-established plants. By the following spring each plant had become a colony consisting of a central stool carrying one to three strong fruiting canes (stem suckers*), surrounded by up to 60 new shoots (root suckers*) arising from the main root system up to 30 inches from the stool. Owing to lack of space it was not possible to replicate the treatments but each colony, fully occupying an area of about 6 ft. diameter, was regarded as an experimental plot.

Two treatments were given to colonies of each variety, namely, pulling out all

* The term " sucker " is often used indiscriminately to refer to any shoot which arises from below the ground. Two distinct types should be distinguished, namely, " root suckers " which develop from adventitious buds on roots, and " stem suckers " which grow from axillary or adventitious buds on the subterranean parts of other shoots. In this series of papers the term " sucker " refers to root suckers except where otherwise stated.

shoots and cutting off all shoots at ground level. Treatments commenced on 29th April, 1953, when all the growths which showed above the ground, i.e. the central stool and all the root suckers, were pulled out from one well-grown colony of each variety. Where a shoot broke off above the point of its attachment, the stump was excavated with a trowel and severed at its junction with the parent root. Removal of a root sucker often resulted in fracture of the parent root at the point of its attachment, even though both parts of the root remained behind in the soil.

The effect of the treatment was to leave a number of root systems *in situ*, with undisturbed assimilating roots, but no longer attached to growing shoots. Judged by the condition of comparable roots on other plants which were excavated and examined, roots left in the soil were clothed with numerous buds and probably bore a few subterranean root suckers which had not yet grown to the surface.

On the same date, on another colony of each variety, all visible shoots were cut off at ground level so that the subterranean base of each sucker and the root system were left undisturbed.

Further colonies of each variety were similarly treated on each of a series of dates until late October. Treatments were thus started while plants were still capable of regenerating from root cuttings, extended through the " off " season when cuttings will not normally grow, and well into the following " on " season. Subsequent behaviour of the treated plants was observed and compared with the growth of undisturbed control plants.

Results of experiments.

Results of all treatments are summarized in Table I. Colonies of both varieties, treated at the end of April, regenerated quickly and strongly from new root suckers

TABLE I.

Summary of the results of treatments in which all shoots were either pulled out or cut off at ground level from well-established raspberry colonies in their second season (one colony per treatment).

Date of treatment (all planted May 1952)	var. Lloyd George		var. Malling Promise		Total new shoots produced by Dec. 1954 in colonies referred to in second column
	Shoots pulled out	Shoots cut off	Shoots pulled out	Shoots cut off	
1953					
April 29 ..	++	++	++	++	147
May 15 ..	+	+	O	++	94
June 5 ..	+	O	+	+	68
,, 12 ..	O	O	O	O	o
,, 19 ..	O	+	+	O	o
,, 26 ..	O	O	O	+	o
July 3 ..	O	O	+	+	o
,, 11 ..	O	+	+	O	o
,, 17 ..	+	O	+	O	2
Aug. 4 ..	++	++	++	++	29
Sept. 4 ..	++	++	++	++	157
Oct. 23 ..	++	++	++	++	212

++ =regenerated strongly, with at least 10 vigorous shoots in the first flush of new suckers.
+ =very few new suckers, which grew weakly at first but ultimately regenerated.
O=died.

which appeared during the following few weeks. No further shoots grew until August, when a new crop of suckers showed above the surface at a greater distance from the stool than those which first appeared. (It is interesting to note that new root suckers usually appear above ground in profusion in autumn and spring in young raspberry plantations, but very few normally elongate and show above the surface in June and July).

Colonies treated in June and July either died outright or regenerated very slowly, from small numbers of weak suckers which appeared only to survive with difficulty. Leaves on such suckers were often juvenile in character and silver-coloured during the first few weeks.

Colonies treated in August produced a crop of vigorous new root suckers, which appeared within four weeks. Those treated in September and October behaved similarly, but with increasingly vigorous and numerous suckers.

Conclusions.

During the autumn, winter and spring, raspberries of the varieties tested can regenerate either from root cuttings or from isolated roots left in the ground. They appear to have a low capacity for regeneration from any type of root in the " off " period, even from large root systems well-clothed with buds and with undisturbed assimilating buds. Although raspberry roots bear numerous visible buds at all seasons, very few seem to be capable of elongating in the " off " season.

DISCUSSION.

Classification of regeneration from roots.

In discussing the behaviour of roots it is useful to classify the main methods by which they can regenerate. Wittrock (1884) defined three types of naturally-occurring " root-shoots " (=root suckers), which he named " additional ", " reparative " and " necessary ". This classification is of considerable interest, but it has not proved adequate for the present purpose, in which a closer analysis is required of the relationships between parent plant (and/or root piece) and the root suckers produced by it.

This relationship may be manifested in the following ways :

Type A. Root suckers growing near the parent plant, to which they normally remain attached, forming an integral part of original plant unit.

Type B. Suckers growing at some distance from the parent from uninjured roots, where the connecting root ultimately dies after the suckers are established.

Type C. Suckers rarely produced, except in response to root injury, though without the roots being wholly severed from the parent shoot system.

Type D. New plants produced from pieces of root severed from the parent, provided the roots remain *in situ* without disturbance of the assimilating root system.

Type E. Pieces of root, severed at both ends and with no undisturbed roots (i.e. root cuttings), capable of producing new plants.

Type F. Roots able to regenerate only after special treatment (e.g. by use of a nurse scion).

Type G. Plants unable to produce root suckers under any circumstances.

Although various intermediate or overlapping types occur, this classification is nevertheless useful in analysing the factors concerned in regeneration. Type A can hardly be regarded as regeneration at all, since no new plant is formed ; Type F need not be considered further at present and G is negative ; but Types B-E are of great interest. It is important to note that in Types B and C the regenerative processes occur from a piece of root which still retains connection both with the parent shoot and with undisturbed assimilating roots. The adventitious bud can thus receive continuous supplies of water and nutrients from established roots as well as elaborated foods from the parent shoot. In D, connection is retained with assimilating roots but not with a shoot, whereas in Type E the adventitious bud, which is the focal point of regeneration, is not connected with either an aerial shoot or an assimilating root system. These distinctions have a bearing on the physiological and anatomical processes concerned in regeneration from roots.

Priestley and Swingle (1929) stated that maintenance of exudation pressure in root tissue probably aids in the initiation and development of buds, which often grow far more readily from an undisturbed root system where only the shoot has been cut away (=Type D). Cairns (1938) found evidence to support this view when severed ragwort roots left undisturbed in the soil (Type D) regenerated more readily than when dug and replanted (Type E).

Pieces of root (true root cuttings) in Type E are entirely dependent upon their own reserves until new organs have been developed, apart from such water and nutrients as the cuttings may be able to absorb from their contact with moist soil.

Seasonal capacity to regenerate.

A long series of experiments at Edinburgh Botanic Gardens showed a well-marked periodicity in the capacity of stem cuttings of many species to root at different times of year (Stewart, 1927) and other references (e.g. Lek, 1934 ; Graham, 1936 ; Deuber and Farrar, 1939 ; and Grace, 1939) suggest that the time of year when stem cuttings are made is one of the important factors in determining their success or failure.

It is clear from the present investigation that the capacity of some species to regenerate from roots also varies from season to season, although this aspect appears to have been little studied. Root cuttings offer a rapid method of multiplying some species, since many cuttings can be obtained from each parent plant after a single season's growth, but successful propagation of species with marked periodicity will depend on accurate knowledge of the extent of their " on " and " off " seasons.

It is easy to distinguish the condition of a shoot (e.g. soft wood, half-ripe, or woody) and thus to give stem cuttings appropriate treatment according to their condition, but it is not yet possible to recognize from appearance whether a root is in the " on " season, or even whether it is suitable for propagation at all. Thus without prior knowledge of seasonal effects, roots may be dug at the wrong time of year when they have little chance of regenerating, and failure may prejudice the propagator against further trials of the use of root cuttings for that species.

References have been found in the literature to some two hundred species said to be capable of regenerating from roots and preliminary work has been done on a number of others in this investigation, but it has not yet been possible to discern any rational basis to account for the behaviour of different species. It cannot be predicted whether or not a particular species can be propagated from roots, or, if so, which type of regeneration is possible or whether the roots will show a seasonal

fluctuation of capacity to regenerate. Yet this information is essential if root cuttings are to be of maximum usefulness in plant propagation and there is need for more work on a wide range of species, propagating each in a wide range of environments and at different times of year.

Regeneration of weeds from roots.

Many plants, including some noxious weeds, regenerate from roots left in the ground after forms of tillage in which the soil may be inverted (e.g. ploughing) or pulverised (e.g. roto-tillage). They may behave in various ways :

Group 1. Some species (e.g. horseradish and dandelion) can regenerate strongly from almost any piece of fleshy root, at all times of year. Pieces of root left undisturbed in the ground below the level of soil disturbance will also regenerate freely provided they are large enough.

Group 2. Other species (e.g. raspberry plants up to 2 years old) regenerate freely at certain times of year, either from root cuttings or from roots severed and left *in situ*, but have an " off " season when they usually fail to regenerate from root cuttings or from undisturbed roots.

Group 3. Ragwort root cuttings exhibit a well-marked periodicity in their capacity to regenerate but the response of undisturbed roots *in situ* is still not clear. It appears that at certain seasons undisturbed roots may regenerate when root cuttings will not.

Group 4. Dock root cuttings do not appear to regenerate freely at any time of year although dock roots which have been severed and left undisturbed *in situ* regenerate strongly.

Further work is in progress to clarify the position regarding Groups 3 and 4 but it follows from the earlier discussion that the rate of regeneration may be affected in different plants by the season when cultivations are done (Groups 2 and 3) or the depth to which cultivation is carried out (Groups 3 and 4).

In ploughing, plant crowns are normally severed with some roots, and inverted, whilst roots below the furrow will be converted into undisturbed Type D roots left *in situ*. If ploughing is deep, the crown will be large, well-supplied with food, and little disturbed relative to the soil, although inverted. It may regenerate freely, but the root systems below the furrow may be small and have difficulty in regenerating because of the depth of soil through which new shoots would have to grow. With shallow ploughing the position is reversed since the crown may be small, much mutilated and less likely to grow, whereas the Type D root systems are not only larger but their cut surfaces are nearer the surface, and more likely to regenerate.

On the other hand, in roto-tillage, the crown is likely to be damaged and bereft of most of its roots, whereas roots in the disturbed zone of soil will be cut up into numerous root cuttings, the size of which will depend upon the speed of travel of the machine relative to the rate of rotation of the blades. Root systems below the zone of cultivation will be comparable with those in ploughing.

Some species (Group 1 above) are likely to regenerate freely both from pieces of root cut up in the process of cultivation and also from whole roots left *in situ* below the level of soil disturbance, irrespective of the type of tillage or date when it is carried out, provided there is moisture in the soil.

Other species (Group 2) may be killed completely even by shallow cultivation

during the " off " season for the species concerned, but will regenerate if disturbed by either type of tillage in the " on " season.

The position is less certain with species in Group 3. Roots which are severed and disturbed in the " off " season are likely to die, whereas roots which are not disturbed, even though cut (i.e. those below the level of soil disturbance) may regenerate provided the undisturbed pieces remaining in the ground are large enough. In that event, shallow cultivation would not necessarily reduce the population, but may even increase it by leaving *in situ* several separate and viable root systems from each parent plant ; whereas deep cultivation might result in the death of all roots, including those remaining below the zone of disturbed soil.

Cultivation of ground containing plants in Group 4 seems likely to kill all pieces of root which are converted by cultivation into root cuttings, but the crown of the plant may regenerate if it is left buried in the soil and undisturbed roots (Type D) may also give rise to new plants.

This investigation is continuing with a limited number of species ; but the present findings have such interesting implications that a similar approach might well be followed elsewhere in the local study of weeds which regenerate from roots following tillage.

SUMMARY.

1. A classification is suggested for different types of regeneration from roots, based on (*a*) the relationships between parent plants and root suckers and (*b*) the circumstances under which the latter may arise naturally, or be induced to grow by suitable treatment.

2. Some species are able to regenerate from isolated pieces of root (root cuttings) at any time of year, under a wide range of environments, whereas in other species the capacity to regenerate follows a well-marked seasonal cycle. All species in the latter group which have so far been investigated show an " on " season in winter and an " off " season in summer. A knowledge of the extent of the " on " season is necessary if root cuttings are to be used successfully in plant propagation.

3. With raspberry, entire root systems severed from the parent shoots in the " off " season, but left undisturbed *in situ*, fail to regenerate or do so only with difficulty, whereas such roots regenerate freely in the " on " season. Other species capable of regenerating from severed roots *in situ* may show similar periodicity ; further work on this aspect is proceeding.

4. The capacity of (*a*) root cuttings and (*b*) severed but undisturbed roots *in situ* to regenerate at various seasons affects the probability of some weed species being killed by cultural operations, the timing of which may be critical for achieving a good kill.

ACKNOWLEDGMENTS.

Acknowledgment is made to my colleagues Mr. I. H. Williams, Miss E. Marshall and others in the Department of Horticulture, who have helped to cultivate and record the large numbers of plants which have been grown in this investigation.

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THE BIOLOGY, LIFE HISTORY AND METHODS OF CONTROL OF THE LEAF CURLING PLUM APHID *BRACHYCAUDUS HELICHRYSI* (KLTB.)

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THE period of egg hatch of aphid species attacking top and soft fruit usually coincides with the period of bud burst of the host plant, and the newly hatched nymphs feed on the young developing foliage. The eggs of *Brachycaudus helichrysi* (Kltb.) which are laid on *Prunus* spp. have, however, been observed to hatch while the buds are still in the dormant stage. Theobald (1) states that the eggs hatch in late February and early March ; Kearns and Morgan (2) have observed that hatching may occur from the third week of January until the middle of February. Observations on the life history of this aphid feeding on damson were carried out from 1952 to 1954, and methods of control by means of insecticides were evaluated under field conditions.

GROWTH STAGES.

During its metamorphosis on *Prunus* spp. the aphid passes through at least 6 and sometimes 7 stages which may be recognized by the following features:

I. *Egg.*

The egg is shiny black, about 0·5 mm. long and 0·2 mm. wide.

II. *Apterous viviparous female* (*Fundatrix*).

Body rounded and very domed, colour varying from dull brownish green to very dark brown, closely matching the colour of the bud scales ; paler cross lines often present, giving a banded appearance. Antennae and legs of same colour as body ; antennae short, about one quarter the length of body, 5-segmented, segments iv and v of about same length, flagellum not more than one and a half times length of basal joint. Legs short, cauda and anal plate hidden under domed body. Cauda rounded, bearing three pairs of lateral hairs. Cornicles very short and wider at base, length same as or slightly less than cauda. Rostrum extending almost to second pair of coxae. Body length 1·7-2·1 mm.

III. *Apterous viviparous female* (*Virgogenia*).

Body less domed than that of fundatrix and more pointed caudally, colour varying from pale green to olive brown ; skin shiny and usually covered with a fine mealy bloom. Antennae longer than those of fundatrix, about half the length of body, 6-segmented, segment iii longer than iv, iv slightly longer than v, v slightly longer than base of vi, flagellum about twice length of base. Cauda pointed terminally, bearing two and sometimes three pairs of lateral hairs. In some specimens cauda and anal plate hidden, but in others projecting. Cornicles variable, some short and thick, others slightly longer, all widening at base. Body length 1·6-1·8 mm.

IV. *Alate viviparous female* (*Summer migrant*).

Head and thorax dark brown to black, dorsal surface of abdomen dark with four pairs of dark lateral patches which narrow posteriorly. Antennae three quarters the length of body, deep brown to black, 6-segmented, segment iii about as long as vi with a number of sensoria, iv with a number of sensoria and about one and a half times the length of v, v longer than base of vi, flagellum almost four times length of base. Legs light in colour with tarsi and apices of femora and tibiae dark. Cauda bluntly elongate with three, sometimes only two, pairs of lateral hairs and one dorso-apical. Cornicles cylindrical and longer than cauda. Body length 1·7-1·9 mm.

V. *Alate viviparous female* (*Return autumn migrant*).

Similar to but slightly smaller than summer migrant. Head and thorax black, abdominal markings similar to those of summer migrant. Antennae slender, three quarters or more the length of body, 6-segmented, segment iv short, about half the length of iii, both with sensoria. Body length 1·4-1·7 mm.

VI. *Apterous oviparous female.*

Small ; body colour varying from pale yellowish green to dark olive brown. Antennae short, about one third the length of body, 5-segmented, segment iii about twice as long as iv, flagellum more than twice the length of base and about same length as iii. Legs short and thick with hind tibia broad, bearing bristles and numerous sensoria. Cauda rounded with two pairs of lateral hairs and one dorso-apical hair. Cornicles short, slightly widened at base. Body length 1·0-1·1 mm.

VII. *Apterous viviparous female* (*Intermediate*).

Body shape and colour similar to virgogenia. Antennae longer and more slender than those of fundatrix, about one third the length of body, 5-segmented, segment iii twice as long as iv, flagellum one and a half times to twice the length of base. Cauda rounded, with two and sometimes three pairs of lateral hairs. Cornicles short and much widened at base. Body length 1·8-2·1 mm.

The comparative lengths of the antennal segments of the various stages are given in Table I.

Table I.

Relative lengths of antennal segments of the stages of B. helichrysi *reared on damson.*

Stage	Antennal segment					
	iii.	iv.	v.		vi.	
			base	flagellum	base	flagellum
Oviparous	9·1±0·3	4·3±0·1	3·6±0·1	8·9±0·2		
Fundatrix	10·3±0·2	5·6±0·1	5·0±0·1	7·1±0·2		
Intermediate	14·7±0·3	6·7±0·2	5·1±0·1	9·0±0·3		
Virgogenia	11·7±0·4	8·8±0·4	7·8±0·2		6·1±0·1	11·2±0·3
Summer Migrant	29·1±0·4	18·6±0·2	11·5±0·2		7·1±0·1	25·7±0·4
Return Migrant	24·2±0·6	13·5±0·4	9·2±0·4		5·5±0·1	23·7±0·5

The general characters of the antennae, cauda and cornicles for the stages are shown in Fig. 1.

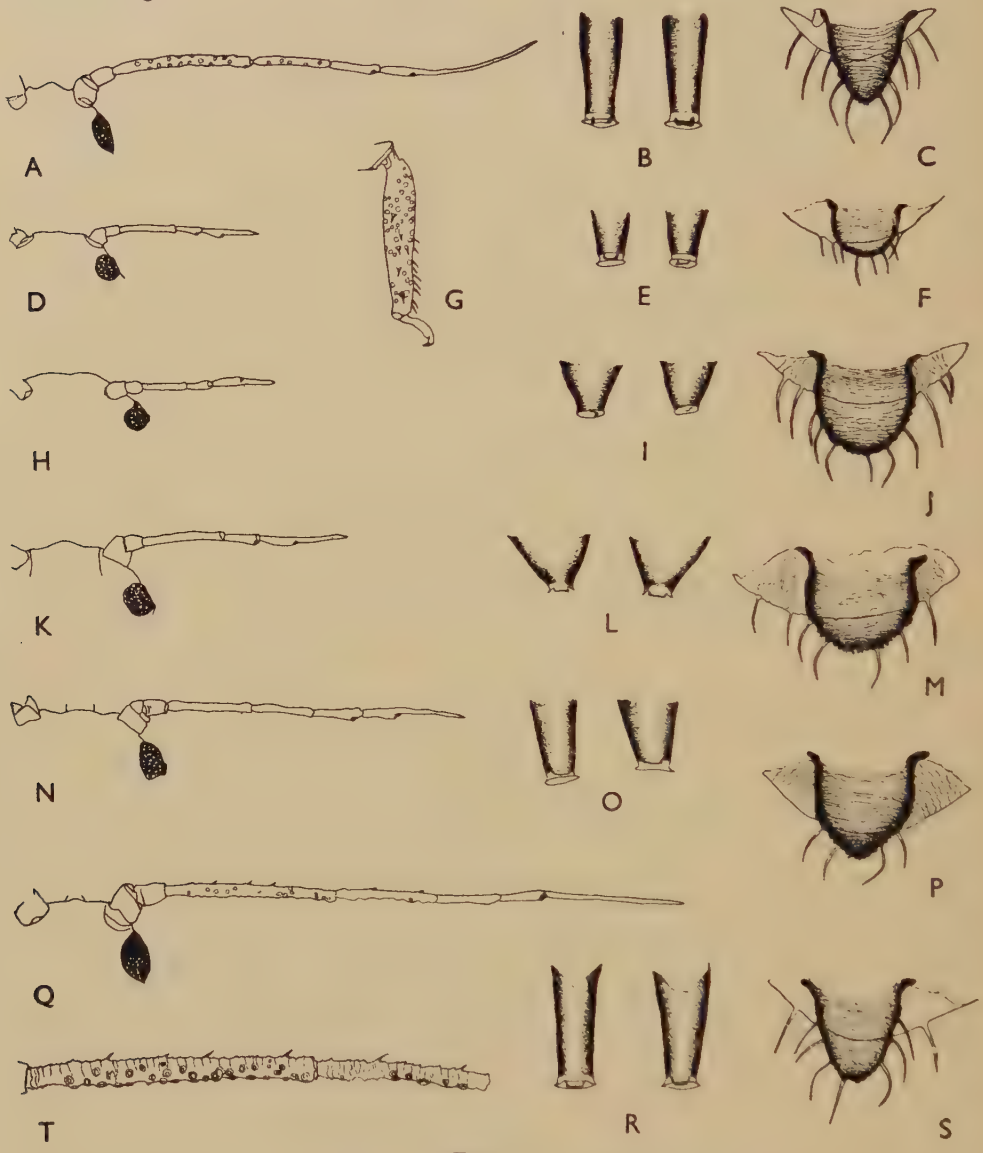

FIG. 1.

Brachycaudus helichrysi (Kltb.).

A, B, C	Antenna, cornicles and cauda of Return Autumn migrant.				
D, E, F, G	,,	,,	,,	,,	and hind tibia of apterous Oviparous female.
H, I, J	,,	,,	,,	,,	of Fundatrix.
K, L, M	,,	,,	,,	,,	of Intermediate.
N, O, P	,,	,,	,,	,,	of Virgogenia.
Q, R, S, T	,,	,,	,,	,,	and antennal segments of iii and iv of Summer Migrant.

Relative sizes of antenna, cornicles and cauda 1:1·4:2·2.

Life history.

Winged migrants fly from their summer hosts to *Prunus* spp. in September and produce the oviparous form. These aphids are small ; they usually feed on the leaves but occasionally on the buds and leaf scars after the majority of the leaves have fallen.

The eggs are deep green when laid and change within a few days to a shiny black. They are deposited in October, the majority being laid singly at the base of or between flower buds. Unlike those of most fruit aphids the eggs hatch soon after being laid ; the shortest time noted was 26 days (laid 10th October ; hatched 5th November).

The nymphs on hatching are green with pale legs and head, but the body changes to a deep green and the head and legs to almost black within 24 hours. The young nymphs wander very little before settling down to feed. They generally insert their stylets into the base of a dormant flower bud. The body colour gradually changes to a dull brownish green or dark brown as maturity is reached. The fundatrix rarely changes its position on the host plant and often passes through all the instars from nymph to adult while feeding on the bud upon which the egg was laid.

The aphids are mature under laboratory conditions within 19 to 27 days and out of doors within 6 to 8 weeks ; virgogeniae are then produced. The young nymphs of this stage often wander short distances before settling down to feed, and several are often found feeding on the same bud. The feeding position on the bud is determined by the stage of bud development, a preference being shown for the softer bud tissue between the outside scales, which becomes exposed when sufficient growth has occurred. On less advanced buds the nymphs are able to feed through the bud scales in the same way as the fundatrices.

The aphids attain maturity by the time the buds burst and the young nymphs then move into the opening buds and feed on the developing leaves. The feeding punctures cause the growing leaves to roll up and provide protection for the developing aphids. With further development of the buds a number of the adult aphids often move into the developing leaves but some remain feeding on the outside of the buds. There appear to be three generations of virgogeniae but there is considerable overlapping of the broods. The winged forms of aphids appear about the middle of May and the majority are winged by the middle of June when they leave *Prunus* spp. for their summer hosts.

Observations were made on damson in two seasons : in 1952-53 they were made until the appearance of the adult virgogeniae at the end of March, and in 1953-54 they were continued until the winged stage in June.

Directly after leaf fall, twigs were collected and examined for the presence of eggs ; records were made of their position, after which the twigs were stuck in damp sand and placed out of doors in a wire-netting cage. Regular examinations were made and the percentage of hatched eggs was recorded.

As soon as hatching had commenced on the caged specimens, random collections of twigs were made from damson trees at approximately fortnightly intervals throughout the season and all aphids were removed and classified into the various stages. Instars of each stage which were bred in the laboratory were examined and described, the characters of the antennae and proboscis being found adequate for separating the instars with reasonable certainty. In common with most species of aphids it was difficult to recognize the change-over from the end of one instar to the beginning of the next.

The life history based on two seasons' observations is shown in Figs. 2 and 3, in

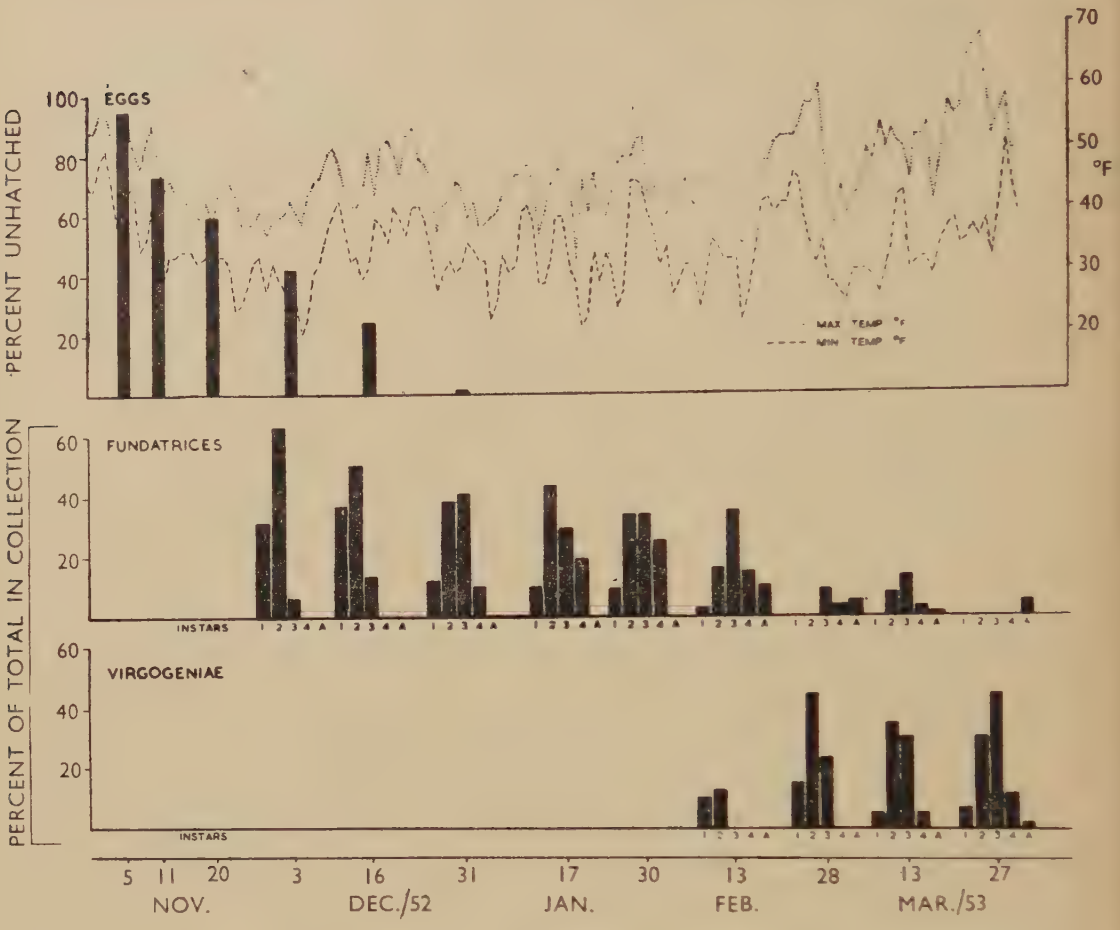

FIG. 2.

Period of egg hatch and proportion of instars of various stages of *Brachycaudus helichrysi* (Kltb.) on damsons, 1952/53. Each instar of each stage is expressed as a percentage of the total number of aphids in each collection.

which the numbers of instars of each stage are expressed as a percentage of the total number of aphids in each collection.

It is evident that, in both seasons, the hatching of the eggs was almost completed by the end of December. In 1953/54 hatching was earlier and was completed by the end of November ; this was probably due to higher autumn temperatures. The more prolonged egg hatch of the 1952/53 season resulted in all instars of the fundatrix stage being present on the trees together, in contrast to 1953/54 when the first and last instars were not present at the same time.

In 1953/54 adult fundatrices appeared as early as December and commenced breeding. The progeny are included in the histograms as virgogeniae although morphologically they were intermediate between fundatrix and virgogenia ; this intermediate form has already been described. The body was the same in shape but

slightly larger than that of the virgogenia ; the antenna was 5-segmented but longer than that of the fundatrix. Adults of this intermediate form gave rise to typical virgogeniae at the time of swelling of the buds, and the young nymphs fed on the most tender portions of the bud scales.

In December 1952 temperatures below freezing did not prevent the hatching of eggs and, though some of the young nymphs died, a high proportion survived. Prolonged cold weather at and below freezing in late January and early February 1954 killed large numbers of aphids and all stages seemed equally susceptible.

It is evident that from a few eggs a build-up of aphids can occur before bud-burst and give rise to a severe infestation in spring. This no doubt explains the extensive damage caused to plums in early spring.

Methods of control.

The Leaf-curling Plum aphid can be controlled by tar oil or DNC/petroleum washes applied during the dormant season. It has been shown (2) that a DDT spray applied just before bud-burst also gave adequate control, but that a DDT benzene emulsion spray containing 0·05 per cent. DDT and a nicotine spray with " Shellestol " wetter at 0·25 and 0·5 per cent. concentration failed to control the aphids when applied at the " cot " split stage. It is evident from the insect's life history that winter washes, though applied as ovicides, are more likely to act as contact insecticides. Experiments in 1952/53 (3) showed that it was possible to obtain complete control of the insect with a tar oil emulsion containing only 0·5 per cent. high boiling neutral tar oil if applied in January after completion of egg hatch. It was also found that a BHC benzene emulsion containing 0·014 per cent. BHC,* and a BHC wettable powder containing 0·013 per cent. BHC were both effective when applied in either mid-January, February or March. A DDT benzene emulsion containing 0·05 per cent. DDT was effective when applied in mid-March.

Experiments with BHC sprays were made in 1954 on a row of standard plum trees of the varieties Belle de Louvain, Pershore Egg, Victoria, Early Laxton and Burbank. The BHC washes were applied in two forms :

(*a*) BHC wettable powder containing 0·013 per cent. BHC.
(*b*) BHC benzene emulsion containing 0·014 per cent. BHC.

0·025 per cent. di-octyl sodium sulphosuccinate wetter was added to each.

The sprays were applied to " run-off " on 12th April at a time when Early Laxton was in full flower and the other varieties were beginning to flower. At this date aphid attack had caused extensive curling of the leaves. Complete control was obtained with both types of spray. It is evident from this experiment that a BHC spray with good wetting properties is able to control the aphids after leaf curling has commenced.

SUMMARY.

1. The diagnostic morphological characters of the various stages of the aphid *Brachycaudus helichrysi* (Kltb.) bred on damson are described.

* Concentrations of BHC are expressed as percentages of the gamma isomer throughout the paper.

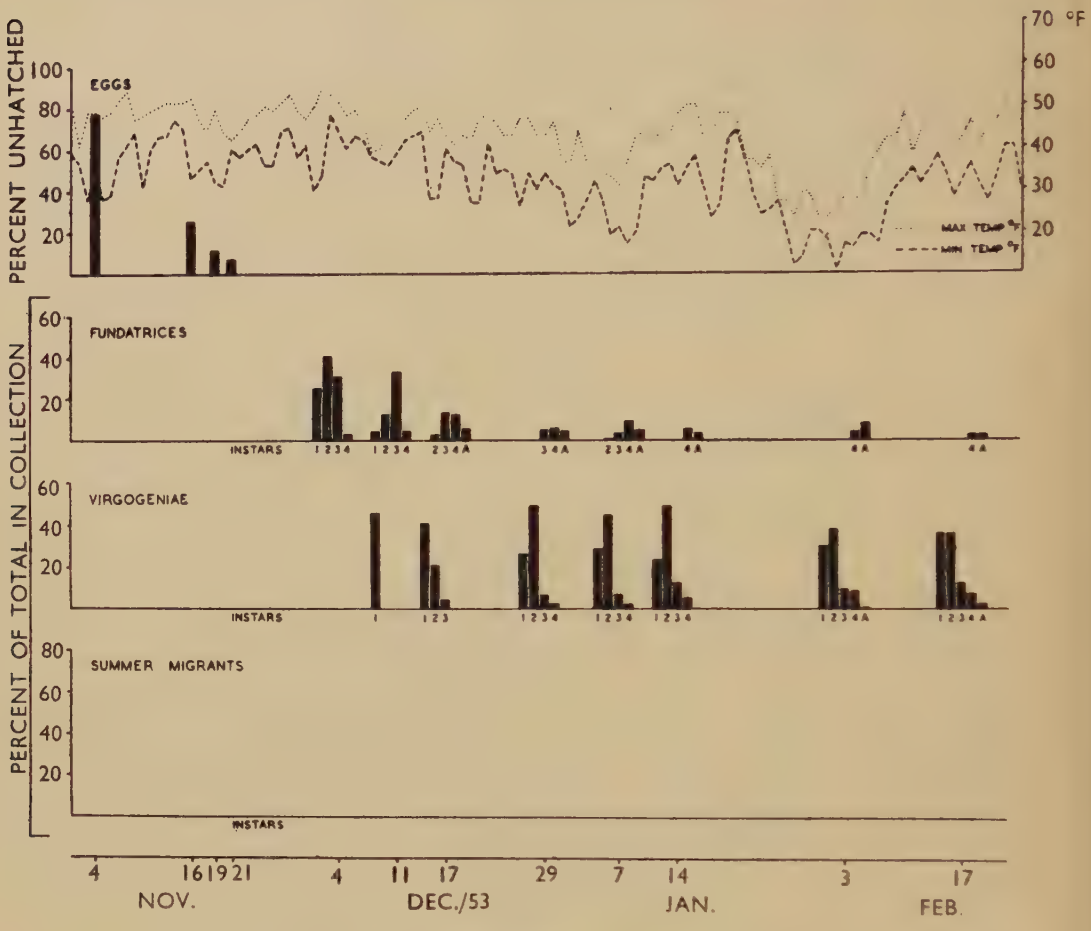

FIG. 3.

Period of egg hatch and proportion of instars of various stages of *Brachycaudus helichrysi* (Kltb.) on damsons, 1953/54. Each instar of each stage is expressed as a percentage of the total number of aphids in each collection.

2. An account is given of the life cycle of the aphid on damson ; it is shown that hatching and reproduction occur before bud-burst of the host plant.

3. Satisfactory control can be obtained with BHC and DDT applied at any time over a long period during dormancy and up to bud-burst, and BHC can provide a control even when leaf-curling has taken place.

ACKNOWLEDGMENTS.

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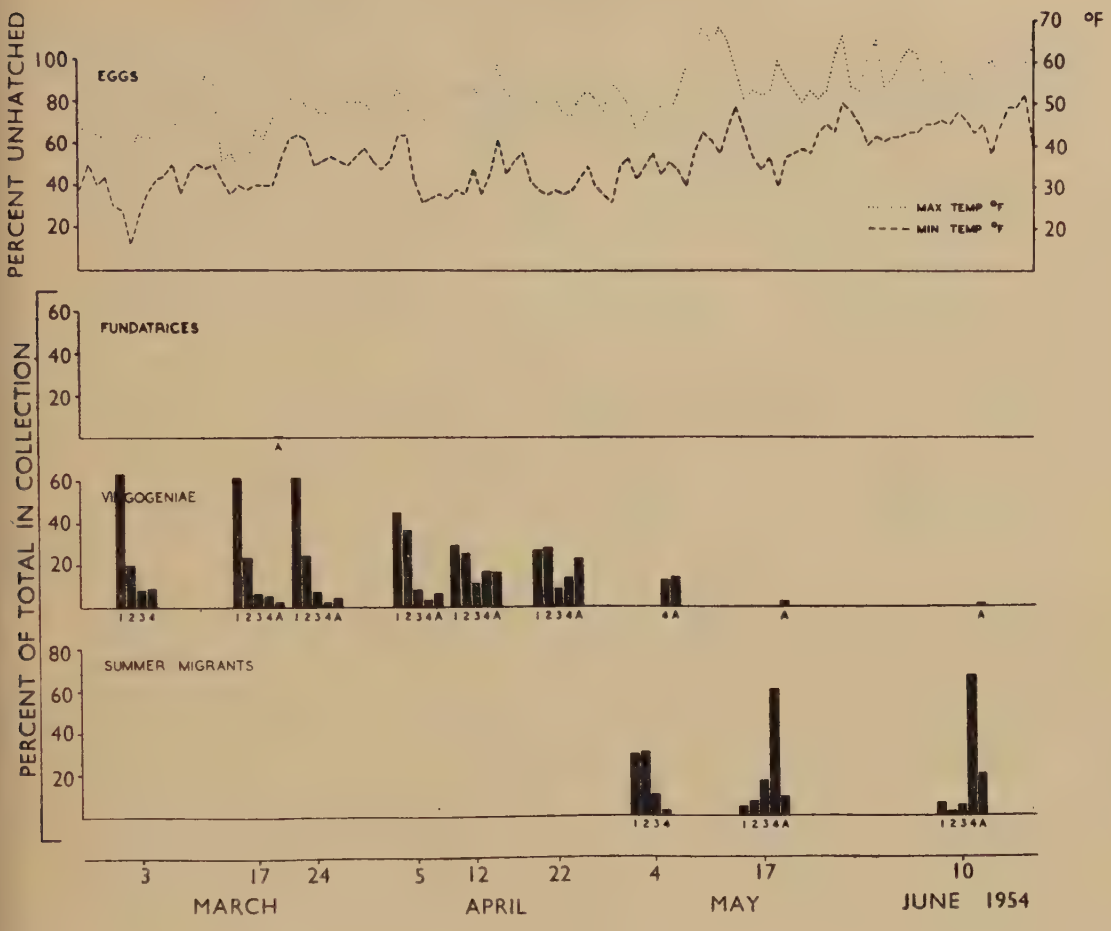

FIG. 3 (*continued*).

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THE APPLICATION OF RAPID CHEMICAL TESTS TO THE DIAGNOSIS OF MINERAL DEFICIENCIES IN HORTICULTURAL PLANTS

III. COMPARISONS OF TISSUE TESTS AND TOTAL ANALYSES FOR POTASSIUM, MAGNESIUM, CALCIUM, PHOSPHORUS AND NITROGEN IN POTATO AND CAULIFLOWER

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In previous papers it has been shown that considerable economy of time and apparatus may be attained by the use of rapid chemical tissue tests in place of ash analyses for determining the mineral status of crop plants (1, 2, 3, 4, 6).

The present paper reports statistical comparisons between the K, Mg, Ca, P and nitrate N contents of extracts of potato and cauliflower leaves prepared in a NIRD macerator, with acetate (Morgan's reagent), citrate, succinate and malonate solutions as extractants. The crops were grown in a long-term manurial experiment (1). In 1952, potato vars. Kerr's Pink and Dunbar Standard were sampled at three intervals during the season and acetate and citrate buffers were used for extraction; in 1953, potato var. Kerr's Pink and cauliflower var. Majestic were sampled on two occasions and succinate and malonate buffers were used to extract the nutrients.

In this paper correlation coefficients between the results of the extraction methods and those of total analysis are given. It is shown that a macerator method followed by extraction with acetate or citrate buffer can replace ash analysis for determining K, Mg, Ca, P and nitrate N in potato ; in potato and cauliflower the nutrients in the malonate or succinate extracts are not so well correlated with the total content.

EXPERIMENTAL.

Materials.

The experimental plot is located at Long Ashton on a calcareous sandy loam derived from red drift overlying Keuper Marl (1). The surface soil contains 2 per cent. free lime and has a pH of approximately 7·2. The following treatments are replicated in each of three blocks : nil, farmyard manure, NPK, NK, NP and PK. The annual rates of application per acre have been : farmyard manure, 10 tons ; nitrogen, 4 cwt. nitro chalk increased to 6 cwt. for cauliflower ; phosphorus, 3 cwt. superphosphate ; potassium, 2 cwt. sulphate of potash.

The following samplings were made :

1952. Kerr's Pink—24th June, 14th July and 21st August.
Dunbar Standard—25th June, 15th July and 22nd August.

1953. Kerr's Pink—18th June and 15th July.
Cauliflower var. Majestic—13th July and 24th August.

Methods for chemical tissue tests and total analysis.

Selection of plant parts.

Details of field sampling methods have been reported in previous papers (4, 6). Mid-stem leaves of potato and first upright leaves outside incurled leaves in cauliflower were sampled at random in each plot. Dust contamination of leaf surfaces was removed with damp cotton wool. Sections were cut across the leaf blades of potato or cauliflower, thus enabling a representative sample to be taken from about 20 leaves. In cauliflower small portions of midrib, about halfway between tip and base of the blade, were also used.

Similar leaf samples were dried and digested with nitric and perchloric acids (1).

Extraction of nutrients.

3 g. of fresh tissue was extracted for 3 min. with 30 ml. of extracting solution in the presence of 1 g. of Darco G 60 carbon in the NIRD macerator. The extract was filtered through ordinary filter paper into a 100 ml. graduated flask and made to volume. The following extracting solutions were used : Morgan's reagent (100 g. sodium acetate per litre buffered at pH 4·8 with glacial acetic acid) ; citric acid (100 g. sodium citrate per litre buffered with citric acid at pH 4·8) ; sodium malonate and sodium succinate (each 1·26 *N* buffered at pH 4·8 with the corresponding acids).

Chemical tests used.

The colorimetric methods used for determining the various mineral nutrients by means of an absorptiometer have been described elsewhere (4) ; K by the sodium cobaltinitrite method, measuring the blue cobalt thiocyanate in acetone ; Ca by dissolving the oxalate precipitate in dilute nitric acid, adding standard $KMnO_4$ and $MnSO_4$ and measuring the residual red colour ; Mg by titan yellow (Grübler grade); P by the vanadate or molybdenum blue methods; N by micro-Kjeldahl.

Total analyses were made by standard chemical methods (1, 4, 6).

RESULTS.

Potato.

The correlation coefficients (*r* values) for total analysis and tissue test data for K, Mg, Ca, P and N in potato are summarized in Table I and illustrated in Fig. 1, a-d.

Table I.

Treatment correlation coefficients between total analysis and tissue test data for potato.

Season	1952				1953	
Variety	Kerr's Pink		Dunbar Standard		Kerr's Pink	
Extracting Solution ..	Acetate	Citrate	Acetate	Citrate	Malonate	Succinate
Element K	0·97***	0·93***	0·93**	0·98**	0·98***	0·98***
Mg	0·94**	0·96***	0·91**	0·93**	0·76*	0·79**
Ca	0·93**	0·98***	0·79*	0·16	0·72	0·62
N	0·96***	0·95***	0·86**	0·95***	0·85*	0·66
P	—	—	—	—	0·78**	0·85**

***, P <0·001 ; **, P <0·01 ; *, P <0·05.

The r values for treatments for the combined samplings are given. The error r terms, other than for Kerr's Pink (malonate extract), are non-significant.

The main points are as follows :

Potassium. The tissue test results are significantly correlated with total analysis data irrespective of crop, variety, extracting solution, sampling or season. The four extracting solutions contained similar amounts of the nutrient.

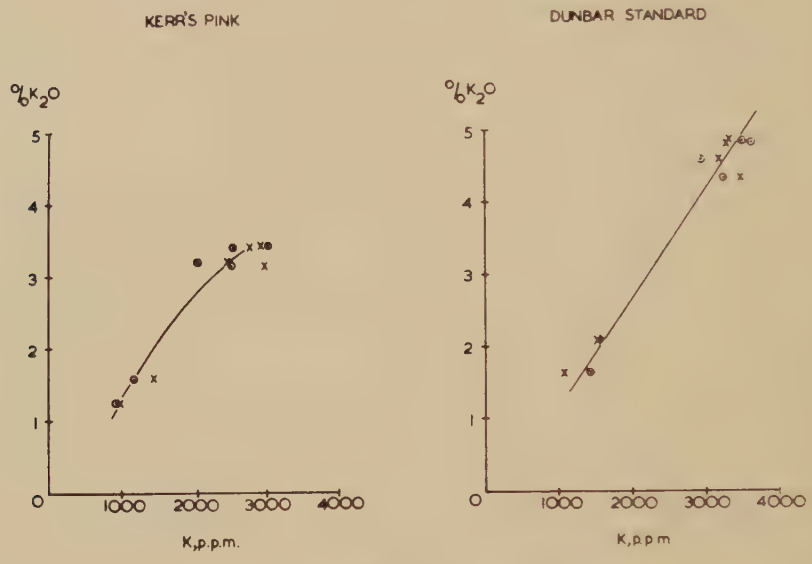

FIG. 1 (a).

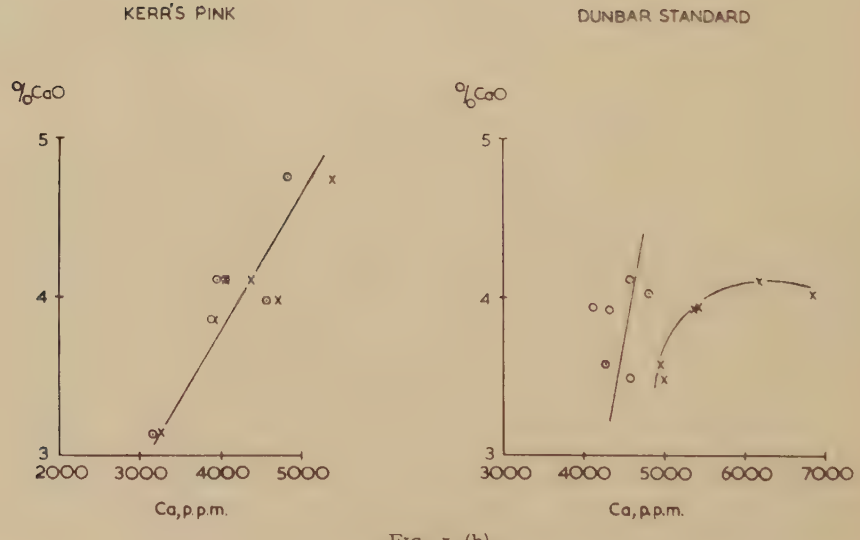

FIG. 1 (b).

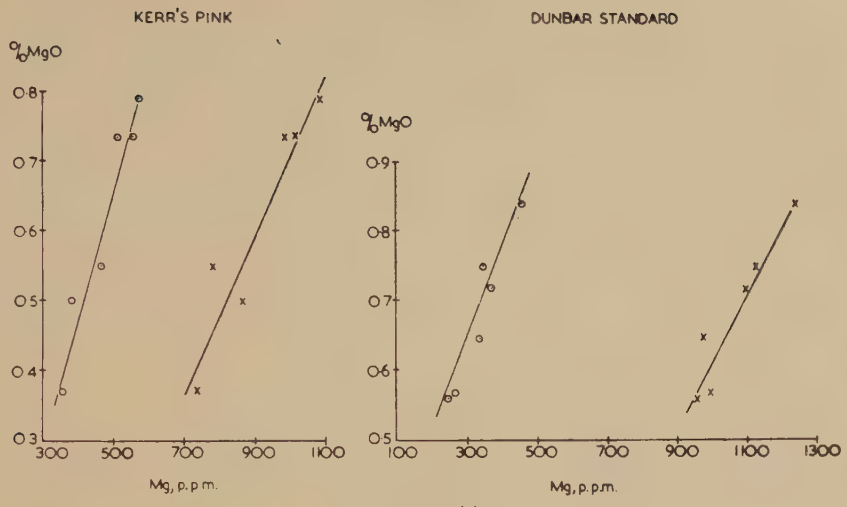

Fig. 1 (c).

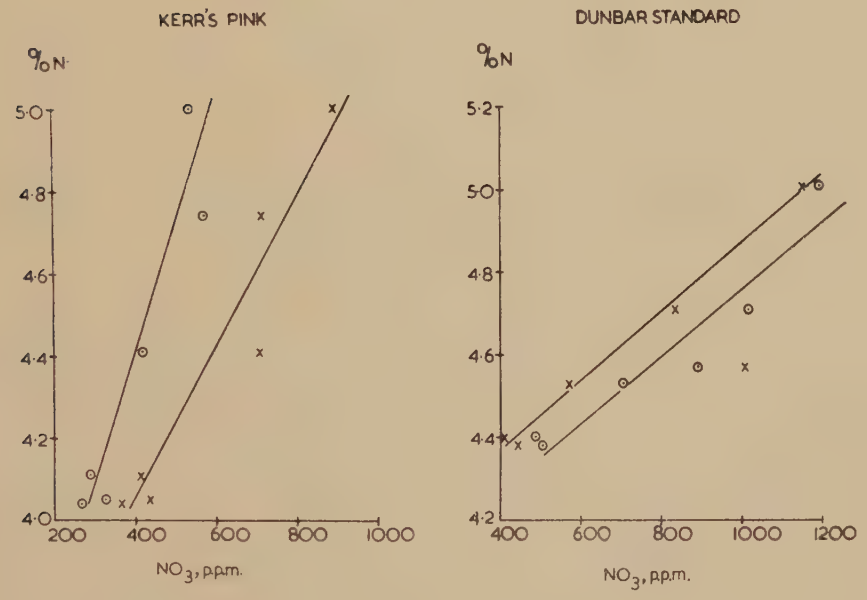

Fig. 1 (d).

Fig. 1.

Relation between K, Mg, Ca and nitrate N (p.p.m. extracted per gm. fresh tissue as abscissae) and total content (% K_2O, MgO, CaO, and N in dry weight as ordinates) in leaves of potato vars. Kerr's Pink and Dunbar Standard.

×, acetate buffer ; o, citrate buffer.

Mean of the replicate treatments for the three seasonal samplings.

Magnesium. The values for the extractant are again significantly correlated with total contents. The malonate extract of Kerr's Pink (1953) has, however, a higher error value and treatment r is lower than for the other methods. Acetate extracts contained significantly more Mg than did the citrate, malonate or succinate extracts.

Calcium. The correlation values for the acetate and citrate extracts are significant in Kerr's Pink (1952). In Dunbar Standard, a later variety, although the acetate correlation is significant, that for citrate is not. The malonate and succinate

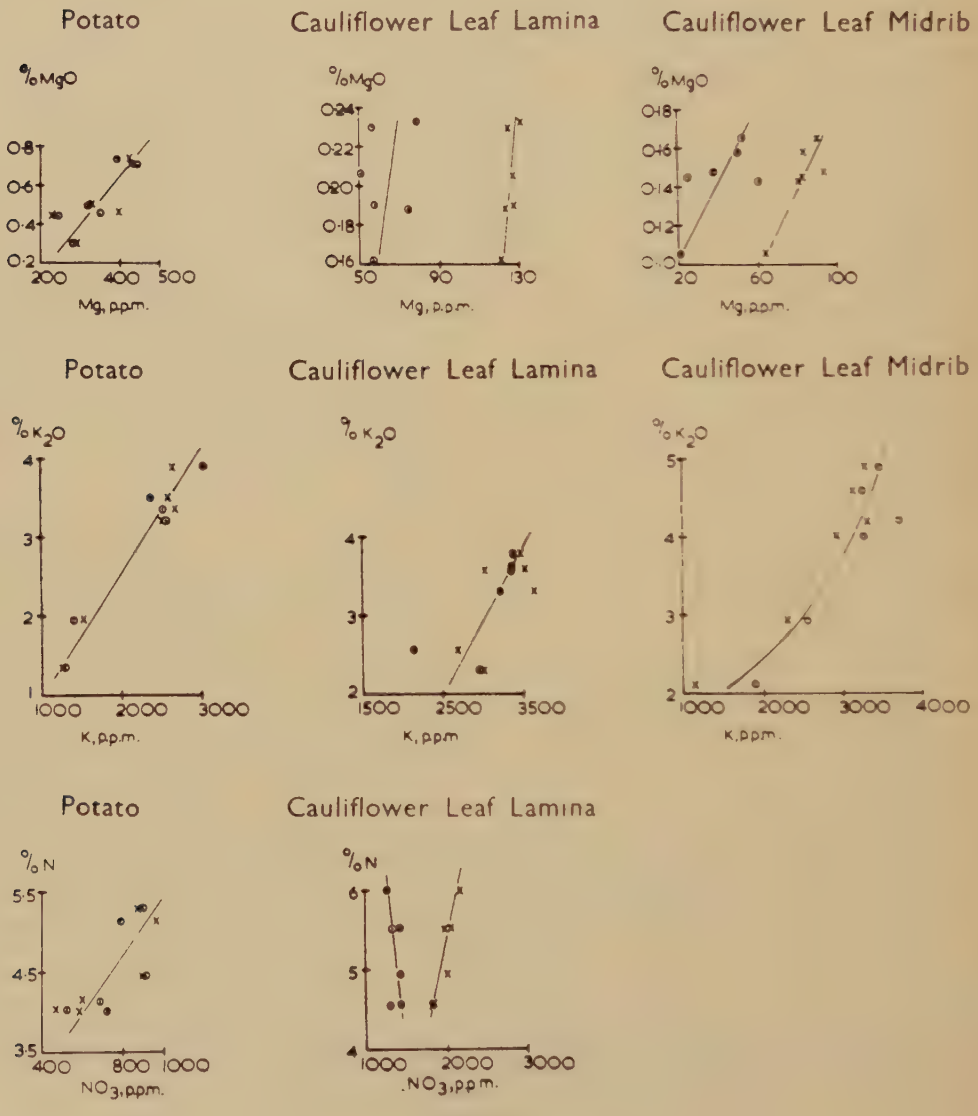

Fig. 2(a).

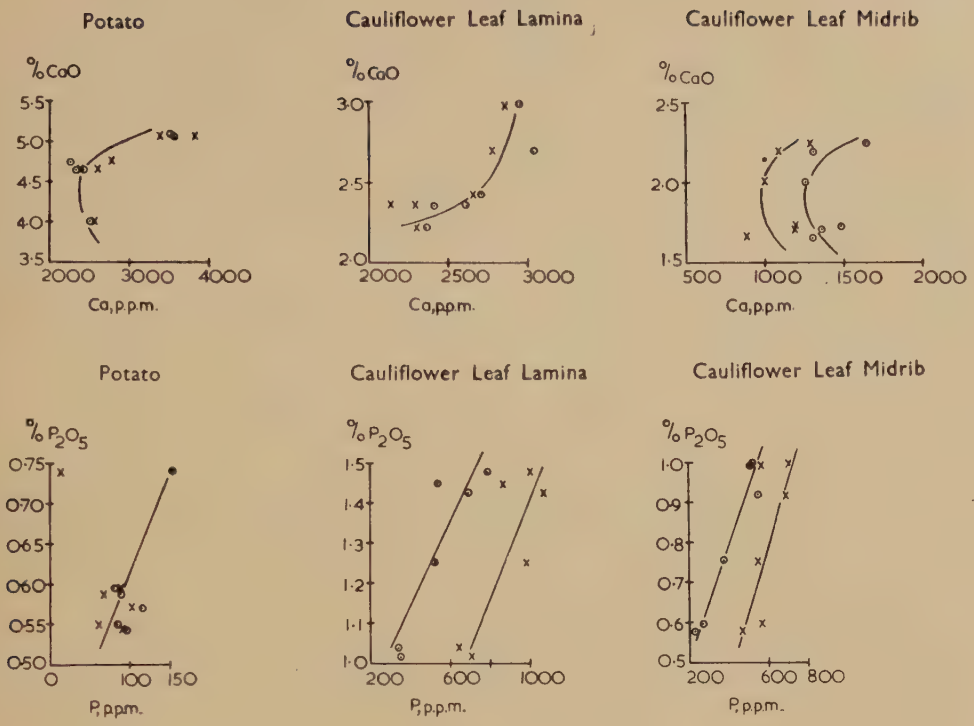

FIG 2(b).

FIG. 2.

Relation between K, Mg, Ca, P and nitrate N (p.p.m. extracted per gm. fresh tissues as abscissae) and total content (% K_2O, MgO, CaO, P_2O_5 and N in dry weight as ordinates) in leaves of potato var. Kerr's Pink and cauliflower var. Majestic (lamina and midrib).
x, malonate buffer ; o, succinate buffer.
Mean of the replicate treatments for the two seasonal samplings.

data are not significantly correlated with the total contents. Acetate extracts of Dunbar Standard contained more Ca than those prepared with citrate.

Nitrogen. The nitrate N values in acetate or citrate extracts (1952) are significantly correlated with the total N for both varieties. Acetate extracts of Kerr's Pink contained more nitrate N than did the citrate ones.

Phosphorus. Treatment r values for malonate and succinate extracts agree closely with the total data. The P contents of both extractants were similar.

Cauliflower.

The correlation coefficients between the K, Mg, Ca, P, and nitrate N contents of the malonate and succinate extracts of cauliflower lamina and midrib and the ash contents are given in Table II and illustrated in Fig. 2, (a) and (b).

Potassium. The malonate and succinate extracts are both significantly correlated with the digest data.

Magnesium. Only the malonate extract of the midrib is significantly correlated with the total content. Malonate extracts contained significantly more Mg than the succinate extracts.

TABLE II.

Treatment correlation coefficients between total analysis and tissue test data for cauliflower.

Extracting Solution ..		Leaf lamina		Midrib	
		Malonate	Succinate	Malonate	Succinate
Element	K	0·87**	0·97***	0·97***	0·93***
	Mg	0·71	0·26	0·85*	0·75
	Ca	0·85*	0·86*	0·30	0·28
	N	0·92**	0·47	—	—
	P	0·82**	0·91**	0·74	0·97***

***, P <0·001 ; **, P <0·01 ; *, P <0·05.

Calcium. Only leaf lamina extracts made with malonate and succinate are significantly correlated with the total content. Malonate extracts contained more calcium than did the succinate extracts.

Nitrogen. Values for nitrate N in the malonate extracts agree well with total N but in the succinate extracts the correlation is poor.

Phosphorus. The values are significant except for the malonate extract of the midrib. Succinate extracts contained more of the nutrient than did the malonate extracts.

DISCUSSION.

One of the aims of this work was to establish whether tissue test data for K, Mg, Ca, P, nitrate N are correlated with total amounts present in the tissues. The amounts of nutrients in the acetate or citrate extracts of potato leaves are closely correlated with digest analyses as shown by significant *r* values for treatments and non-significant ones for error. The treatment values indicate that the results of the quick methods are well correlated over a wide range of mineral status. This has confirmed previous work, with a range of crops, in which the nutrient contents of acetate extracts were significantly correlated with the total contents (1, 2, 3, 5). Malonate or succinate buffers, however, have not proved as satisfactory as the acetate extractant. The correlations for Ca and Mg in malonate or succinate extracts of potato and cauliflower are poor.

It is of interest that the K contents of the tissues examined are similar, irrespective of the extractant used, and are all significantly correlated with total contents. This indicates that K is readily extracted under a variety of conditions and is therefore not so tightly bound in the tissues as are other nutrients.

The data again confirm the value of using quick chemical tests in place of the more tedious procedures of total analysis for the diagnosis of the mineral status of crop plants.

SUMMARY.

1. Correlation coefficients (*r* values) were determined for the major nutrients in fresh tissue extracts and in acid digests of potato, vars. Kerr's Pink and Dunbar

Standard, and cauliflower, var. Majestic. The crops, which were grown in a long-term manurial experiment, were sampled at intervals during 1952 and 1953.

2. In 1952, K, Mg, Ca and nitrate N in acetate and citrate extracts of potato leaves are significantly correlated with the digest data except for Ca in Dunbar Standard.

3. In 1953, the nutrients in the malonate or succinate extracts of potato Kerr's Pink do not provide as good a correlation with total analysis as those extracted in acetate solution.

4. In 1953, K, Ca and P in extracts of cauliflower leaves made with either malonate or succinate are significantly correlated with total analysis. Nitrate N, in the malonate extract alone has a significant r value with total nitrogen. The Mg in either extractant is not correlated with the total content.

5. Leaf lamina extracts of cauliflower show similar correlations with the total nutrient content as do the extracts of the midrib.

6. Extraction of leaves with acetate or citrate buffers in the NIRD macerator is recommended as a quick method for determining K, Mg, Ca, P and nitrate N in potato leaves, since the results are well correlated with total contents of the nutrients in the tissues. Nutrients in the malonate or succinate extracts provide less significant correlations with total analysis.

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THE INFLUENCE OF SOIL ENVIRONMENT ON THE BEHAVIOUR OF APPLE AND PLUM CUTTINGS

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THE previous paper (Garner and Hatcher, 1955) described investigations at East Malling on the regenerative behaviour of hardwood stem cuttings, the ultimate aim being to extend this method of propagation to all the main fruit-tree rootstock varieties. The selection of varieties for intensive experiment and the production of source shoots in adequate numbers culminated in a full-scale comparison of different cutting types, including their reaction to growth substance treatment. The next step was to obtain information on the influence of soil environment, since an understanding of the interplay of all factors is a necessary prerequisite for the understanding and control of the rooting process.

An accepted attribute of the woody cutting is that it may be planted outdoors, though it does not follow that natural conditions, either of climate or soil, are optimal. Soils may vary widely and some therefore be more suitable than others. Winter cold or summer drought may affect success and may to some extent be ameliorated by appropriate techniques. Some of these variables are examined in the present paper, in which results of trials on three soils, two at East Malling and one at Boskoop, are presented.

The events leading to the collaboration between Dutch and English workers are in themselves of interest. The construction of the terraced island at Bradbourne, East Malling (Garner and Hatcher, 1949; Furneaux, 1954) had been a primary reason for the English authors visiting Holland where, at the Nursery Research Station at Boskoop, some work had already begun on the propagation of Malling rootstocks by cuttings. The need for joint research was clear, for the two experimental approaches were quite distinct, Boskoop's main concern being to determine the growth substance requirements of many species and varieties (de Boer, 1955), whereas East Malling used fewer plants for wider studies. There was also the striking similarity between the strip polders at Boskoop, with their constant water table, and the design of the terraced island at Bradbourne. Furthermore, the Boskoop practice is to store cuttings over winter to avoid frost-lifting, to which their rather shallow-planted cuttings (as suiting the high water table) are particularly prone. Finally, soil conditions at Boskoop appeared so very favourable, and the ease of digging up rooted cuttings so conducive to experimental observation, that it was natural to include the Boskoop environment in the general analysis.

EXPERIMENTAL.

In brief, four kinds of cutting of each of three rootstock varieties were observed under four sets of conditions, with the effect of a standard growth substance treatment being noted throughout. The experiments were continued over two successive years. (Fig. 1.).

The varieties were Myrobalan B and Brompton plums, and Malling Crab C apple, as in the earlier East Malling experiments. Each was available from three sources: hedge shoots grown specially for cuttings, layer shoots from the nursery beds, and bedded stock shoots from newly established plants. Two kinds of cutting were made

2 Seasons	1949–50 ; 1950–51			
3 Rootstocks	Myrobalan B plum, Brompton plum, Crab C apple			
4 Types of cutting		Second 2 Basal 1	— Basal 3	Second 4 —
	Shoots of	Hedge	Bedded Stock	Layer
2 Treatments	O and G O, without growth substance G, with growth substance (specification : instantaneous dip, indole-3-butyric acid (IBA) ½ mg./ml. 50 per cent. alcohol)			
4 Environments	Spring planting following winter storage	+	+	—
	Autumn planting	—	+	+
	Soil :	Boskoop polder	Bradbourne island	E. Malling loam
6 Replicates	Unit plot of 10 cuttings			
10 Cuttings	Total number of experimental cuttings, excluding guards, 11520			
Main data	Observations on cuttings after winter storage Condition of cuttings in early summer Rooting, survival and growth of cuttings			

Fig. 1.

The experimental pattern.

from each type of shoot, basal and adjacent second, i.e. six in all. Only four kinds, however, could be used and the basal layer cuttings (to avoid the etiolation effect discussed by Garner and Hatcher, 1955) and the second bedded stock cuttings were discarded.

The design was in the form of randomized blocks, with separate lay-outs for each variety and soil ; on Bradbourne island randomized pairs of blocks corresponded with the two planting times. The unit plot was a half-row containing 10 cuttings spaced 5 cm. (10 cm. at Boskoop in second year) between cuttings and 15 cm. between rows. In 1949 the source shoots were collected on 14th November and, in 1950, between 20th and 22nd November. Cuttings were 30 cm. in length, any remaining leaves being removed, and those for storage waxed at the top. Growth substance treatment was then applied where required and the cuttings arranged in four sets.

One set was carefully packed and sent to Boskoop where the cuttings were stored vertically in soil (Fig. 6), frost protection being afforded by reed mats. Another was stored similarly in loam soil at East Malling. The remaining sets were planted immediately, one on Bradbourne island and the other in East Malling loam soil. Stored cuttings were planted at Boskoop and Bradbourne in spring.

The main features of the Boskoop soil are its high proportion of peat (30 per cent.) and its water table, which is maintained at some 18 inches from the soil surface, a situation in which cuttings are never subjected to drought. The Bradbourne island " soil ", artificially constructed from lake-bed silt, is a highly calcareous silt loam with an admixture of organic matter. Water is conducted into the subsoil of the island by a series of pipe lines spaced at 20 foot intervals (Garner and Hatcher, 1949) but its water holding and conducting capacity, though high, is variable and the hoped-for watertable has not materialized. The loam soil of the Roseacre series, Sandgate Beds (Furneaux, 1954) is a fine sandy loam, well drained in its surface layers but with a somewhat retentive subsoil, a combination generally considered highly suitable for nursery work.

Observations included a summer census, and a final record of establishment and growth after one year. At Boskoop all cuttings were lifted and their roots graded.

RESULTS.

Condition of cuttings after storage.

Storage ended with renewal of bud activity in the spring, this being later in 1951 than 1950, a retardation paralleled in rooting condition.

Myrobalan B, much the earliest variety, had in 1950 opened its buds by 10th March. Callusing, while general, was most advanced in basal cuttings which had received growth substance. Some of the treated cuttings were already rooted ; these were mostly hedge cuttings. In 1951, on 10th March, when the buds were just bursting, no rooting was visible though there was a pronounced growth substance stimulation of callusing.

Brompton cuttings were examined on 29th March in both years, by which date in 1950 the buds were opening and, in 1951, still swelling. Callusing was moderate in both years, but only in 1950 was any rooting visible, this being confined to a few treated cuttings.

Crab C cuttings were similar in bud condition to Brompton but there was only slight callusing, with an occasional cutting beginning to root.

At East Malling, in the spring of 1951, many cuttings were blackened at their base, this being attributed to water-logged conditions. At Boskoop, also, winter rainfall in the second season was excessive, so that planting was delayed until 18th April.

Condition of cuttings in early summer.

The summer census of the cuttings provided a link between the spring observations (see above) and the final record at the completion of growth in autumn. Many of the plums were showing new growth in early June, thus indicating root action below ; indeed, all those destined to root were extending, the question being what proportion would succeed (Table I). With Myrobalan, the chance of success was

Table I.

Ratios of cuttings finally rooted to those extending in early summer.

Soil Environment	Myrobalan B		Brompton		Crab C	
	O	G	O	G	O	G
Boskoop	0·74	0·82	0·84	0·80	—	—
Bradbourne stored ..	0·82	0·83	0·39	0·79	7·71	2·50
Bradbourne not stored	0·58	0·58	0·49	0·68	1·68	1·24
East Malling	0·96	0·87	0·56	0·67	0·91	0·86

G, treated with growth substance.
O, not treated.

generally good, except in those cuttings which had been planted in autumn on the island ; but with Brompton, the effects of soil and growth substance treatment were in part still to show, the stimulatory and beneficial effect of the latter countering the hazards of the open environment. Clearly the developmental condition was so much more advanced in Myrobalan B that the only residual influence was the detrimental effect of the island medium.

Retardation was much more extreme in Crab C apple, for not only were few cuttings showing shoot extension, thus heralding the low proportion of eventual rooting, but the initial extension phase was incomplete, and soil and growth substance effects were reflected in the actual stage reached.

Rooting of cuttings.

Data are presented pictorially (Fig. 2), each small diagram showing the percentage rooting of one kind of cutting in the four environments (BOS, Boskoop, stored ; BI–S, Bradbourne island, stored ; BI, Bradbourne island, not stored ; EM, East Malling loam, not stored). To construct the diagrams, site means are plotted from the intersection points of lines at right angles, the four positions so obtained being joined to form a quadrilateral. Quadrilaterals relating to presence or absence of growth substance treatment are superimposed, shading of the overlapping areas showing a beneficial effect. Area is a measure of rooting, shape reflecting environmental influence, with a square denoting uniformity of behaviour. Varietal means, each derived from four kinds of cutting, are summarized in Table II.

Myrobalan B.

The variable size and shape of the diagrams show a wide range of behaviour. In 1949-50 there was good rooting at Boskoop and on the East Malling loam, but a much poorer performance on the island which winter storage before planting helped to redress. In 1950-51 there was a marked reduction in rooting at Boskoop and on the loam.

Source influence was strong, the bedded stock basal cutting being much the poorest, especially in the second year. Second cuttings were often superior to basal, this showing well with non-treated cuttings in the first year ; the exception was with autumn planting on Bradbourne island, where the thinner second cuttings were particularly prone to a detrimental soil influence. In the second year the hedge

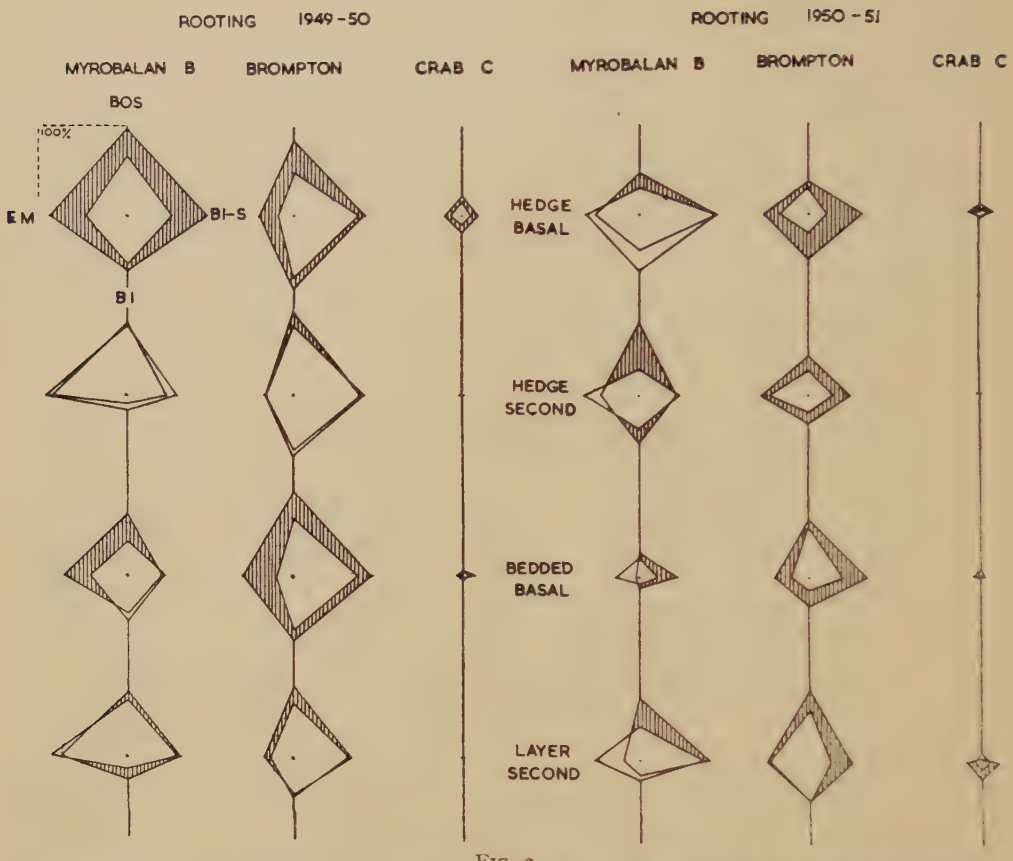

FIG. 2.

Diagrammatic presentation of rooting data (see Table II for means of all types of cutting). BOS, Boskoop (stored) ; BI–S, Bradbourne island (stored) ; BI, Bradbourne island (not stored); EM, East Malling loam (not stored).

second cuttings were relatively much more resistant, but after winter storage the outstanding cuttings were hedge basal and layer second.

The cuttings were sensitive to growth substance treatment. In the first year basal cuttings responded much more than seconds. Hedge basals showed improved rooting on all soils though, with autumn planting at Bradbourne, only limited effect was observed. On this soil, bedded stock basals did not respond and evidently these conditions do not favour growth substance stimulation. Boskoop soil was undoubtedly excellent in this respect but, whereas in 1949-50 the loam soil behaved likewise, in 1950-51 the growth substance treatment consistently depressed rooting. Where a beneficial response was obtained in the second year, notably at Boskoop, seconds as well as basal cuttings reacted; indeed it was the former which showed remarkable improvement.

Brompton.

At Boskoop and on the island, fairly good rooting in the first year was followed by a marked fall in the second whereas, on the East Malling loam, there was the

Table II.

Rooting behaviour (percentage rooted) on different soils. Average values for all types of cutting.

Season	†	Variety	Boskoop	Bradbourne		East Malling
				Stored	Not stored	
1949–50	O	Myrobalan B	61·7	51·3	33·7	68·5
		Brompton	61·6	71·2	60·4	23·7
		Crab C	5·8	6·2	2·8	3·3
	G	Myrobalan B	80·4***	59·2 n.s.	35·0 n.s.	82·1*
		Brompton	86·2***	77·1 n.s.	64·6 n.s.	41·7**
		Crab C	6·7 –	6·2 –	5·3 –	7·1 –
1950–51	O	Myrobalan B	29·2	54·1	32·5	49·6
		Brompton	41·7	26·3	24·6	35·0
		Crab C	2·9	5·4	4·2	4·1
	G	Myrobalan B	55·4***	60·0 n.s.	30·0 n.s.	28·4**
		Brompton	55·0**	53·3**	39·6**	47·1**
		Crab C	4·6 –	10·0 –	8·3 –	9·6 –
1949–50	Soil Mean		50·4	45·2	33·6	37·7
1950–51	Soil Mean		31·5	34·8	23·2	29·0

† { G, treated with growth substance.
O, not treated.

Level of significance of treatment effect for each soil :
***, P <0·001 ; **, P <0·01 ; *, P <0·05 ;
n.s., not significant ; –, not analysed.

reverse effect. The reason for this was the scanty growth made by the cuttings in 1949-50, so that many of them were classified as alive but non-rooted. Preliminary winter storage appeared to be somewhat beneficial to cuttings planted on the island, though this effect was not significant, and the implication is that they were fairly tolerant of these soil conditions.

Source influence was weak, the rooting diagrams being similar. Significant differences were found but they only emphasize that no cutting was consistently poor. Thus in 1949-50 it was the layer second cutting which rooted least well, yet in 1950-51 this same cutting was best.

Brompton cuttings responded well to growth substance. In 1949-50, when non-treated cuttings rooted quite well, marked improvement was obtained at Boskoop and on East Malling loam, but not at Bradbourne. In the second year, however, when non-treated cuttings rooted poorly, there was strong positive reaction to growth substance on all three soils, intensfied at Bradbourne by preliminary winter storage. Further, whereas in the second year both basal and second cuttings were stimulated effectively, in the first year the response was predominantly by basal cuttings.

Crab C.

The diagrams show the paucity of rooting of this apple rootstock under all the conditions applied. There was little difference between soils, winter storage conferred only limited benefit, and Boskoop gave rather low values in 1950-51. In both years basal cuttings rooted to some degree, hedge more than bedded. No second cuttings

rooted in 1949-50, but in 1950-51 layer seconds were best of all. There was a beneficial response to growth substance.

Growth of cuttings.

The pictorial presentation of the growth data is the parallel of that for rooting (Fig. 3), as is the summary of varietal means in Table III. The similarity of shape of the diagrams within a variety and within any season shows that soil and seasonal differences were much larger than differences between the types of cutting.

In 1949-50, there was generally vigorous growth at Boskoop and, at East Malling, quite good growth on the island but little on the loam. This contrast was particularly striking with Myrobalan B plum where the average values, including cuttings with and without growth substance, ranged from 141 cm. down to only 25 cm. The limited growth on the loam was a definite effect of seasonal drought for in the following year, with a more adequate rainfall, the average growth on this soil

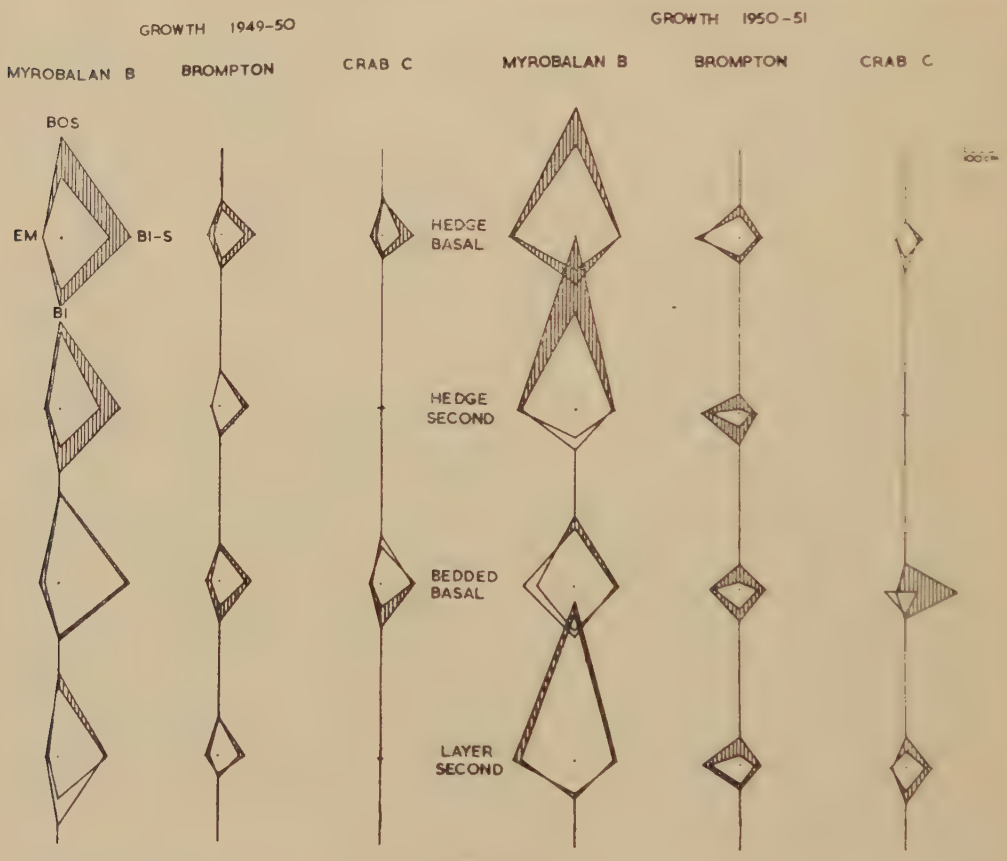

Fig. 3.

Diagrammatic presentation of growth data (see Table III for means of all types of cutting). BOS, Boskoop (stored) ; BI S, Bradbourne island (stored) ; BI, Bradbourne island (not stored) ; EM, East Malling loam (not stored).

Table III.

Growth behaviour (length in cm. of primary shoots) on different soils. Average values for all types of cutting.

Season	†	Variety	Boskoop	Bradbourne		East Malling
				Stored	Not stored	
1949–50	O	Myrobalan B	128	89	94	25
		Brompton	57	43	44	14
		Crab C	70	42	35	12
	G	Myrobalan B	154*	111**	103**	26–
		Brompton	63 n.s.	53**	55**	19–
		Crab C	61 –	56–	67 –	14–
1950–51	O	Myrobalan B	170	68	70	95
		Brompton	19	26	32	54
		Crab C	30	26	47	25
	G	Myrobalan B	229 n.s.	74 n.s.	67 n.s.	98–
		Brompton	44*	35***	49***	60 n.s.
		Crab C	45 –	54–	47 –	18–
1949–50	Soil mean		88·8	65·7	66·3	18·3
1950–51	Soil mean		89·5	47·2	52·0	58·3

† G, treated with growth substance; O, not treated.
Level of significance of treatment effect for each soil :
***, P <0·001 ; **, P <0·01 ; *, P <0·05 ;
n.s., not significant ; –, not analysed.

approached 100 cm. and exceeded that on the island, where there was less growth than in 1949-50. At Boskoop, on the other hand, growth considerably exceeded that of the first year.

Brompton cuttings on the loam, like Myrobalan B, responded to the higher rainfall in 1950-51. On the other hand, in this second year, their growth was less both at Boskoop and on the Bradbourne island. Crab C apple cuttings were least affected by seasonal climate, showing limited growth on the loam in both years, but at Boskoop a decline in the second.

It has already been remarked that source effects on growth were small, though some interesting differences were seen. In 1949-50, basal Myrobalan B cuttings made significantly more growth than seconds on the island and on the loam, but in 1950-51 at Boskoop a reverse effect occurred. With Brompton significant differences were found on all soils in 1949-50, though these were not consistent.

There were significant responses in growth to growth substance treatment. Hedge cuttings of Myrobalan B were stimulated in their growth in 1949-50 at Boskoop and on Bradbourne island, in 1950-51 only at Boskoop. On the loam soil there was no response. Neither bedded stock basal cuttings nor second layer cuttings showed any definite reaction. The effect on Brompton cuttings reflected that already observed on rooting, though it was less striking. In the first year response was predominantly by basal cuttings, whereas in the second year both basal and second cuttings reacted. Because only few Crab C cuttings rooted, comparisons are impossible. Storing the cuttings and delaying planting had no effect on growth.

Observations on rooting at Boskoop.

Root growth was assessed in five categories from " heavy ", scoring five points, down to " slight ", scoring only one ; typical plants are shown in Fig. 7. In Fig. 4 the cumulative percentages of rooted cuttings are plotted for the plum varieties ; passing from category " 5 " downwards, the greater the percentage at any stage the more prolific is the root system. Myrobalan B cuttings developed more vigorously in the second year, Brompton in contrast much less so. The effect of growth substance treatment was well defined.

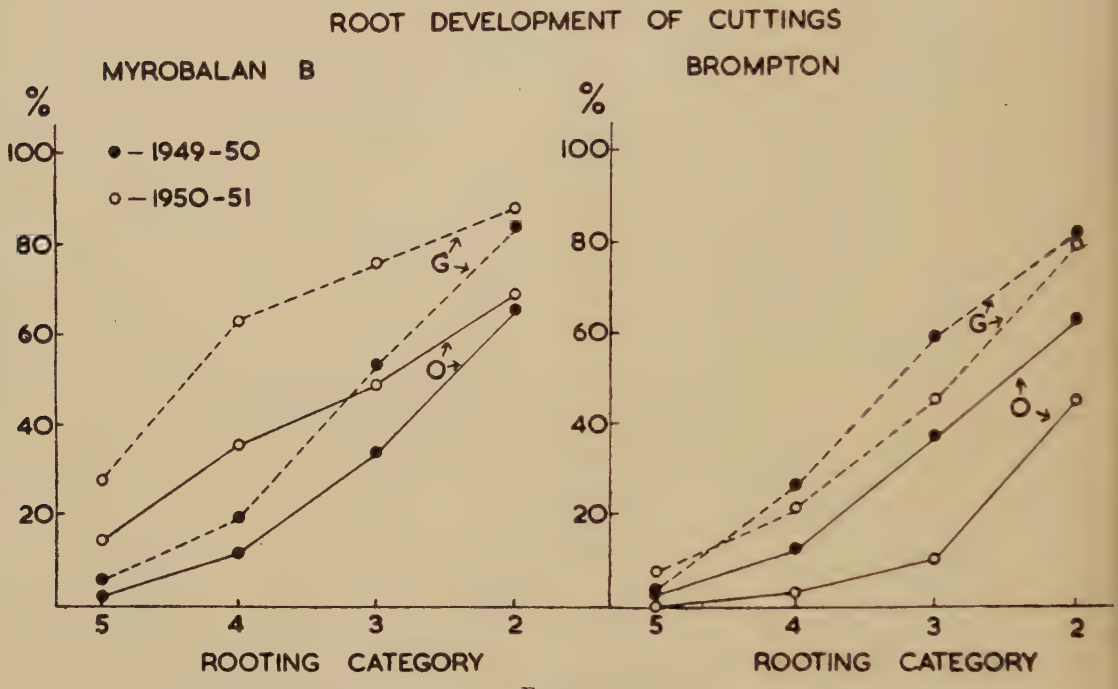

Fig. 4.

Assessment of rooting at Boskoop. Cumulative percentages in the rooting categories. G, treated with growth substance ; O, not treated.

For comparative purposes indices have been calculated, the index being defined as the percentage of rooted cuttings scoring at least three points (Table IV). There is a positive correlation of this rooting index with shoot growth (Fig. 5), with an interesting varietal contrast. In Myrobalan B there is linear relationship throughout, but in Brompton this is not so, for while the rooting indices range up to seventy per cent., at about half this level shoot growth approaches its maximum and becomes an insensitive character.

These observations may be linked with those previously made on shoot growth. Thus in Myrobalan B the greater shoot development in the second year accompanied greater root development, and similar parallels may be drawn between sources, such as between the heavy shoot growth response of second cuttings to growth substance in 1950-51 (mean 287 cm.) and the high rooting indices (mean 82·8 per cent.). With

Table IV.

Rooting indices of plum cuttings at Boskoop.

Variety	Season	†	Rooting Indices				
			Hedge basal	Hedge second	Bedded basal	Layer second	Mean
Myrobalan B	1949–50	O	35·0	29·8	42·8	29·7	34·3
		G	67·2	43·7	51·2	46·8	52·2
	1950–51	O	47·1	33·3	30·8	72·7	56·0
		G	66·4	85·4	50·0	80·3	70·5
Brompton	1949–50	O	20·5	47·1	35·0	40·4	35·7
		G	69·2	56·1	67·8	42·9	59·0
	1950–51	O	17·6	0·0	8·8	12·1	9·6
		G	52·4	38·5	47·4	42·6	45·2

† G, treated with growth substance ; O, not treated.

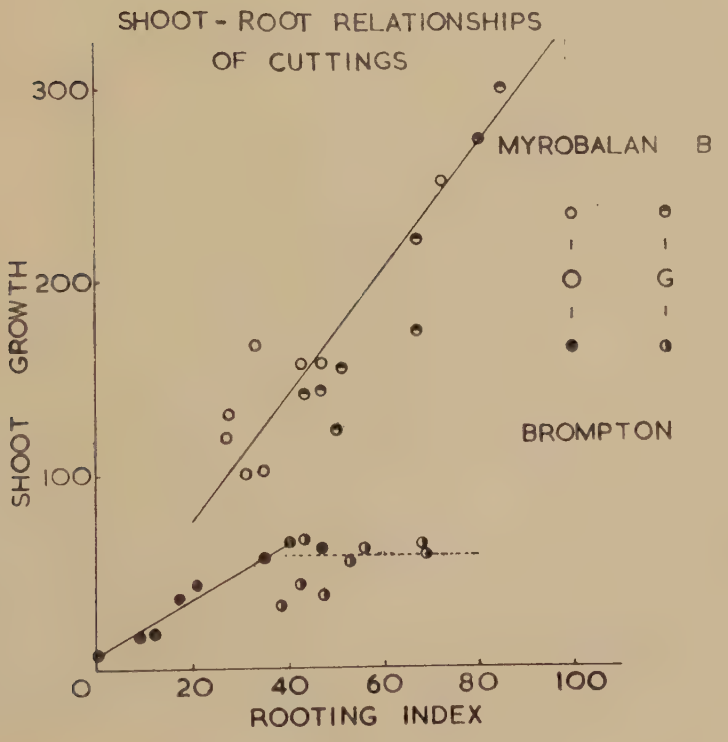

Fig. 5.

Relationship between shoot growth and root development of cuttings at Boskoop.

Brompton in 1950-51, when the mean rooting index of non-treated cuttings was only 9·6 per cent., there was a significant growth substance stimulation of shoot growth, whereas in 1949-50, when the mean index was 35·7 per cent., there was no significant effect. The same parallel may be extended to the other two soils, shoot growth in 1950-51 on the loam being quite insensitive to growth substance, whereas at Bradbourne, when rooting of non-treated cuttings was poor, there was a very highly significant growth substance reaction.

For Crab C the data are too fragmentary for close comparisons, but it should be noted that the greater shoot growth in the first year's experiments was associated with a mean rooting index of 80 per cent., compared with only 50 per cent. in the second.

Survival of non-rooted cuttings.

Some cuttings, though failing to reach the arbitrary establishment threshold of 5 cm. shoot growth, remained in a healthy condition throughout the season (Table V). Few Myrobalan B cuttings survived, the most of them in 1949-50 on East Malling loam where growth conditions were poor. More Brompton cuttings survived, and likewise the highest number was on the loam in the first year. Crab C cuttings

Table V.

Mean percentage survival of non-rooted cuttings after one season.

Variety	O	G	Maximum survival
Myrobalan B	3·1	2·2	13·7
Brompton	18·1	12·7	52·1
Crab C	28·0	21·7	67·1

G, treated with growth substance ; O, not treated.

survived best, but the highest values were linked with source and not with soil differences. In the first year, hedge cuttings survived best but, in the second, the layer second cuttings gave the higher values, just as they had given the better rooting percentages.

In general more non-rooted cuttings survived in 1949-50 than in 1950-51 for all three varieties (overall means of 17·4 and 11·3 per cent. respectively), and cuttings stimulated by growth substance survived least well.

DISCUSSION.

The magnitude of soil influence depends not only on the characteristics of the soil but also on the nature of the cutting. There is a consistency about the kind of influence, however, which renders it possible to assess the relative suitability of a number of soils. Thus, the peat soil at Boskoop is highly suitable, East Malling loam less so, and the lake-bed silt on the Bradbourne island distinctly unfavourable. Furthermore, climatic conditions may have modifying effects, either directly on the soil itself, as for instance the drought effect on the loam in 1950 or the waterlogging at East Malling and at Boskoop in 1951 ; or indirectly, as for instance the seasonal decline in rooting observed in the second year on all soils.

PLATE I

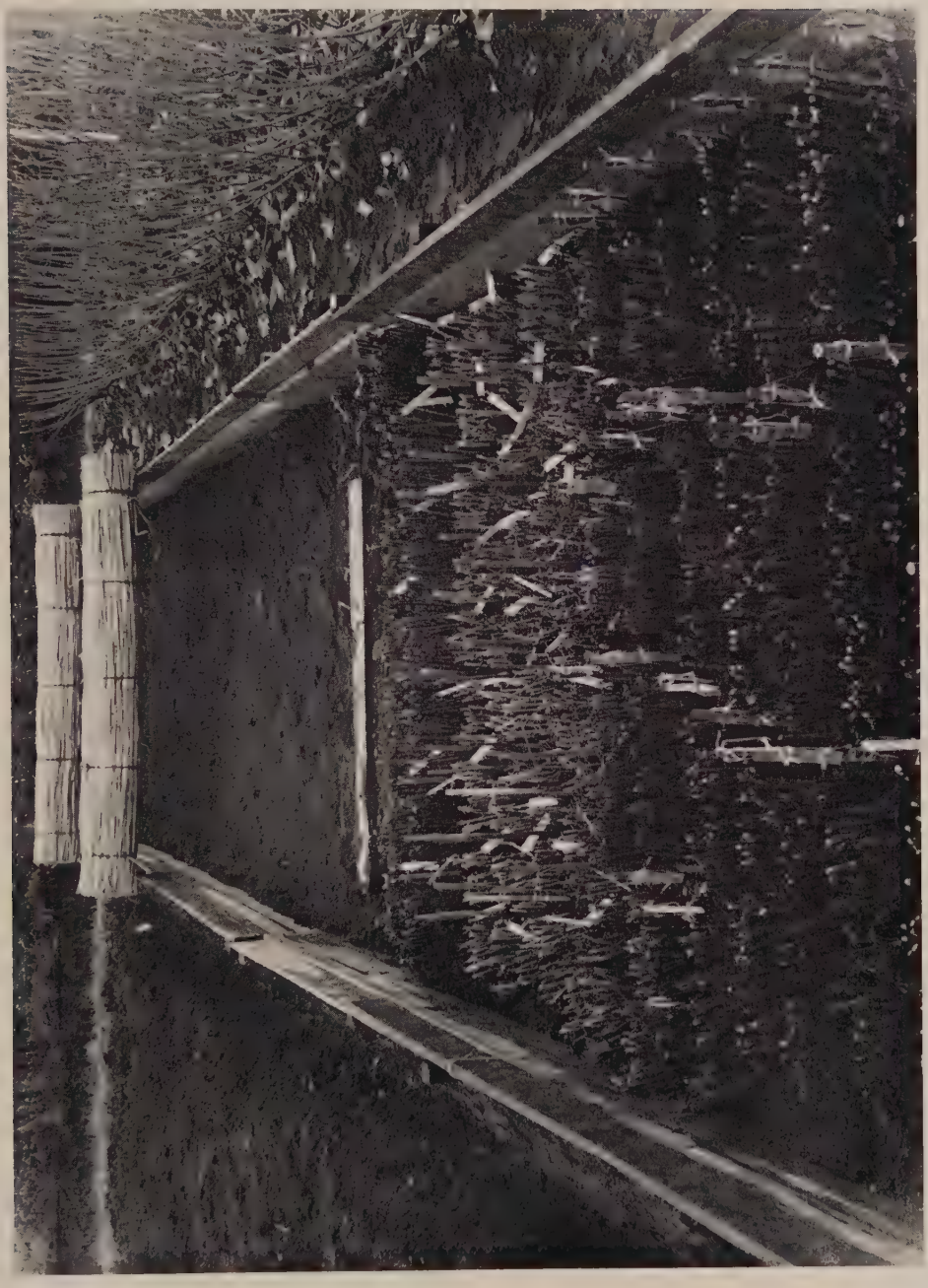

Fig. 6.
Method of storing cuttings at Boskoop in unheated frames with reed mats for frost protection.

[face p. 278

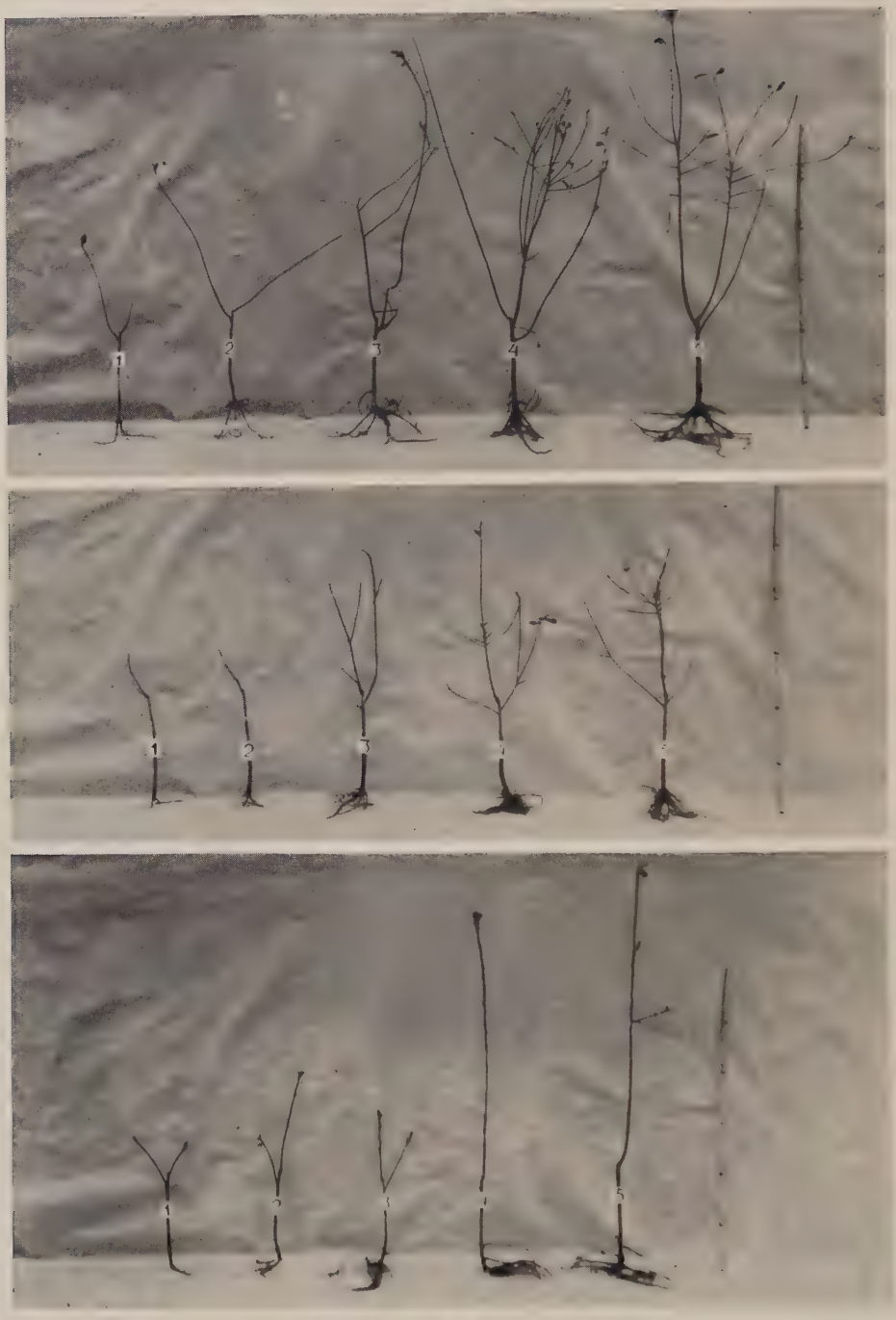

FIG. 7.

Categories used in assessing rooting at Boskoop with scores from one to five points according to amount of root development.

Top row	.. .. ..	Myrobalan B
Middle row	.. .. ..	Brompton
Bottom row	.. .. ..	Crab C

Given favourable conditions Myrobalan B cuttings rooted well and readily, but not when they were unfavourable. Wide fluctuations in behaviour could be attributed also to source factors and to response to growth substance treatment, with interaction effects between them all. Thus, basal cuttings from bedded stock shoots were poor propagators (confirming Sinha and Vyvyan, 1943), especially in a year (1950-51) when the level of rooting was low, whereas upper cuttings were reduced in rooting from 80 per cent. to 15 per cent. by changing the soil environment. The differential effects of growth substance were also striking ; thus the effect was highly beneficial at Boskoop, insignificant on the Bradbourne island, and actually depressing in 1950-51 on the loam. Then in relation to source, basal cuttings in 1949-50 reacted much more strongly to growth substance than did upper cuttings, whereas, in 1950-51, response was far more general. In a similar way Myrobalan B cuttings also fluctuated in their growth, the soil effect, with marked seasonal interaction, predominating. The favourable nature of the Boskoop soil was shown, not only by the vigour of growth, but by the response to growth substance, confined almost entirely to hedge cuttings. There was a high correlation between shoot and root development.

Brompton cuttings were much more tolerant of the island conditions, and differences between cutting types were smaller with no source conspicuously inferior to any other. Their range of reaction to growth substance was narrower, the general effect being highly beneficial. Growth was less and with smaller fluctuations, but its scantiness on East Malling loan in 1949-50 should be noted. Other features in common with Myrobalan B were the reduced rooting in the second year and the seasonal characteristics in growth substance response, namely, the marked response of basal cuttings in the first year and the more general response in the second.

In no circumstances did establishment of Crab C apple reach thirty per cent., and though fluctuations could be associated with the different factors—soil, season, source and growth substance—the outstanding feature was the general deficiency of rooting. In behaviour the cuttings were stable, non-responsive to the favourable conditions at Boskoop, tolerant of the island, and insensitive to changes generally.

The characteristic behaviour of these rootstocks therefore shows itself not only in relation to soil differences, but also to various rooting factors. Myrobalan B is the most sensitive variety, Crab C the least. Furthermore, sensitiveness and rooting propensity appear to be related, Myrobalan B being the ready-rooter and Crab C the shy-rooter, with Brompton somewhere between.

It would, however, be fallacious to assume that, because Crab C cuttings were insensitive to their surroundings, this variety is less selective than Myrobalan B. Rather it appears that the quality of sensitivity should be related not so much to the particular variety, but to the level of rooting it achieves. A ready-rooting variety is naturally sensitive and amenable to control, but a shy-rooting variety can only respond following an additional sensitizing treatment.

The mere provision of favourable soil conditions is, however, inadequate to induce prolific rooting in the shy variety. Previously (Garner and Hatcher, 1955) it was suggested that Crab C is inherently slow to root and that favourable conditions are usually of inadequate duration. Survival of the unrooted cutting through a growing season, however, normally ensured effective rooting during the second winter, Crab C surviving best as in the present experiments (Table V). What is required for such a variety is an acceleration of the rooting to bring it within the compass of the period of dormancy before Spring bud-burst. One natural variable is temperature,

and it is pertinent that in the year when rooting and bud development were retarded, the mean soil temperature during November and December was 5°F. lower. Such likelihood of a temperature limitation in open soil suggests at once the need for temperature control, during a preliminary storage period before planting.

Already the effects of a storage treatment during the winter have been observed ; indeed it was the examination of cuttings after such storage that first revealed the retarded development in the colder year. At Boskoop too, winter storage is the traditional method for hardwood cuttings, the medium being the normal soil on which is placed the covered frame to give frost protection. The cuttings planted on the Bradbourne island, however, were not stored in the same soil but in loam, thereby partially avoiding the island's deleterious influence. Subsequent growth of these cuttings, however, was not improved by storage, so that the inimical effect was on root initiation. The winter storage of large numbers of cuttings, as well as being convenient, is therefore sometimes necessary.

If, in addition, soil temperature were to prove the critical and limiting factor in the rooting behaviour of hardwood cuttings, preliminary storage with temperature control would be of the greatest help. All the interacting factors to which Crab C has proved insensitive would then assume a new importance.

ACKNOWLEDGMENTS.

The authors wish to place on record sincere appreciation to their respective Directors, Professor F. G. Gregory, F.R.S., Dr. E. F. Jacobi and Dr. F. R. Tubbs, for sanctioning this international collaboration.

SUMMARY.

1. Hardwood cuttings of selected rootstock varieties were planted on three soils, a strip polder at Boskoop, an artificial island at Bradbourne, East Malling, and a loam at East Malling.

2. Myrobalan B plum cuttings rooted readily but were sensitive to source condition, growth substance treatment and soil environment. In 1940-50 rooting was good both at Boskoop and in East Malling loam though, in the latter, seasonal drought resulted in scanty growth. Bradbourne island soil proved injurious, especially to second cuttings.

3. Brompton plum cuttings rooted well, with no regular source differences, and tolerated better the adverse island conditions. The drought effect in 1949-50 on the loam was again observed.

4. Crab C apple cuttings rooted poorly and were the least sensitive to soil environment. Non-rooted cuttings survived better than did those of the plums.

5. The cuttings likewise varied in sensitivity to growth substance, their response also reflecting the soil differences and those attributable to source and seasonal variation.

6. Observations at Boskoop showed correlation between root and shoot development.

7. A seasonal reduction in rooting was probably associated with colder soil and soil temperature may have limited the rooting of Crab C.

8. Storage of cuttings prior to planting has proved not only practicable but necessary, for in addition to avoiding adverse open soil conditions, it is of great potential value in providing opportunities for better environmental control in the early life of the cutting.

9. The sensitivity of cuttings to soil environment is discussed.

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(*Received* 16/4/55.)

BOOK REVIEWS

A SURVEY OF THE AGRICULTURE OF KENT. By G. H. Garrad. (London : Royal Agricultural Society of England, W.C.1. 1954. Pp. 232, illus. Price 21s. 0d.)

The Royal Agricultural Society of England are to be congratulated on initiating a series of Surveys, and in choosing G. H. Garrad as their surveyor for the County of Kent. They could hardly have chosen anyone with a wider experience of agriculture in his own county, as the very nature of his work has taken him into every parish and every type of farm, and this book is proof of the very wide knowledge that he has acquired in his travels.

In reading this book I have been filled with a pride for my county in the contribution it has made to agriculture as a whole, and with a greater understanding for the wide variety of her agricultural pursuits.

Although there are some interesting notes on the older history of agriculture, such as the iron-smelting industry and the cloth mills of the High Weald, the old Kent plough, etc., this book is a survey of agriculture as it is today, showing the changes that have taken place during the last 35 years. It has some attractive illustrations, and is well supplied with maps. The effects of two world wars, of the changing emphasis from pasture to arable and from one type of stock to another are clearly shown. The impression I am left with is that this has had the effect of invigorating the industry, and of forcing the farmer " out of the rut " to make the fullest use of his land in times of danger.

Mr. Garrad has used extensively the Ministry of Agriculture 4th June returns. This should reassure farmers that, intelligently used, these returns are of real value. At times I think he has used them too extensively, tending to turn his survey into a mathematical table but, if one abhors figures and percentages as I do, one can always skip them and turn to Mr. Garrad's excellent summaries.

These tables do reveal one disquieting fact, which everyone should take to heart. Between the years 1914 and 1949, 93,126 acres of land were lost to agriculture in the County of Kent alone. This is a staggering figure and, in spite of the Town and Country Planning Act, this wastage is still going on.

Of the individual chapters, I was most interested in that on geology, which is most clearly written, and is the most important in the book, because if one understands the make-up and the origin of the different soils, then one can understand and read the complex plan of the industry. As the writer says, the maps 1 and 2 (geology and physiography) must be studied together. What a pity that they were not printed opposite each other, instead of back to back.

After the chapter on geology, the author deals with the pattern of farming on the different soil series. This is followed by chapters on the separate branches of agriculture. I found that on fruit disappointing and rather uninspiring ; I suspect that Mr. Garrad's interests were more in stock farming, because these chapters, and especially the one on sheep, are excellent reading.

The main value of this book is that it will place on record for future generations a true picture of the countryside and of the state of agriculture at this time. Imagine

what we should have missed if we had not had Cobbett's " Rural Rides " to give us a picture of the countryside of England in his day. I therefore hope the Royal Agricultural Society of England will take courage from this venture and extend the Survey to every county in England.

If " to know more intimately is to love more deeply ", then I can recommend this book to all whose livelihood is in the land of this " Garden of England ".

J.W.S.M.

THE DAHLIA GROWER'S TREASURY. By A. T. Barnes. (London : W. H. Collingridge, Ltd. 1954. Pp. 160, illus. Price 15s.)

This is certainly a mine of information on the dahlia for, in addition to the necessary knowledge of its cultivation, a great deal of time and patience must have been needed in tracing records, checking references, etc., to give so much detail and cover such a wide range. This reviewer only hopes the book will be fully appreciated.

Though, no doubt, many will appreciate and find interest in much of the " details ", it is the " culture " that will appeal to most.

In describing " Growing for Exhibition " the author is on very safe ground, having been among the successful leading exhibitors for many years. New exhibitors will find here many useful hints to interest and guide them, the outcome of experience gained by the author over a long period ; but I feel the advice to remove the back florets of a bloom to reduce the size is highly dangerous, the practice being almost certain to be detected by a good judge. I also cannot agree to the suggested method of cutting blooms for showing on the morning of the show. A much safer way is to cut the flowers the previous evening after sundown and place in deep water in narrow vessels in a cool place. The flowers will benefit from the good drink, and possible damage from wind and rain during the night, as so often seems to happen before a show, will be avoided.

I liked especially the chapter on Floral Art, by the author's wife, who has been a most successful exhibitor for quite a long time. Many useful tips are given in this section, which no doubt will encourage many to take up dahlia growing for this purpose.

The monthly calendar of operations should prove a very good guide for amateurs, especially the reminder to inspect tubers in December and January, when trouble is most likely to occur.

The advice on buying plants is very sound, if intending purchasers want to avoid disappointment.

It would be very risky to store tubers under the staging of a cold greenhouse as advised in the section on Storage (p. 33). No doubt a slightly heated greenhouse was intended.

To give over 27 pages (and a 4-page index) to varieties seems unwise, considering the number of new varieties introduced each year, many of which will supersede existing ones ; thus many in the list may be out of general commerce shortly.

Propagation in all forms is fully dealt with and should be easily followed. Many readers will be encouraged to try growing from seed when they realise that it can be sown in the open ground.

The heavy outer stakes (illustrated opposite p. 48) are not essential ; with a

stout centre stake those surrounding can be of bamboo, which will give a much neater appearance.

Apart from these few criticisms, I consider this is certainly the best book on dahlias, and I sincerely hope it meets with success. E.R.L.

THE PRUNING OF FRUIT TREES. By Paul Champagnat. Translated and edited by N. B. Bagenal. (London : Crosby Lockwood & Son, Ltd. 1954. Pp. 166, illus. Price 12s. 6d.)

The subject matter of the book is divided about equally between general observations on tree growth and detailed descriptions of pruning methods. More space is given to trained trees than to commercial tree forms. The book probably contains the most comprehensive account in English of the classical French pruning methods, and their modern adaptations. Various types of pyramid, cordon, espalier and palmette are described, in addition to some of the more unusual shapes such as the top, and the vase or goblet. For these forms Lorette pruning is required, but simpler methods are recommended for recent developments of the trained tree, such as the runaway palmette and some of the arched tree forms that are allowed a greater degree of freedom in their growth than was formerly the case. Excellent descriptions are given of how the various tree forms are built up from the maiden, and of how they should be pruned in later years ; both these stages are illustrated by clear and ingenious diagrams to show the sequence of operations under varying conditions of growth. So often when the amateur attempts to prune a tree in accordance with printed instructions, he finds himself faced with a set of circumstances not envisaged by the writer, but Monsieur Champagnat, from his wide experience, clearly describes what action should be taken under most of the foreseeable circumstances. This approach will be of the greatest help to the beginner in the art and will set him well on the way towards becoming an expert.

The original book contained sections on the anatomy and physiology of fruit trees, including discussions on such matters as the transport of water and elaborated food materials, and the effects of pruning on the distribution of growth hormones. While selecting, on the whole, the most practical parts of the book, Mr. Bagenal has included much that will appeal to professional fruit growers interested in the basic principles underlying pruning. The chapters on shaping natural tree forms, arching, and pruning for fruit are especially valuable from this point of view.

A few inaccuracies that have arisen through difficulties in translation may be observed as, for example, the surprising statement in the first chapter that root hairs are inserted at intervals of about half an inch, whereas the author describes these hairs as being inserted over a root length of about one to two centimetres (roughly half an inch) close behind the root cap. The word " annulation ", used several times in the text and in the legends to the illustrations, does not immediately call to the mind of an English reader the idea of the formation of bare areas of wood, though it is true that an explanation of the term is given when it is first used. But these are relatively unimportant matters and there is no doubt that this most readable book is excellent value at its moderate price of 12s. 6d. It is likely to appeal to all those who are keenly interested in fruit growing and, in particular, to those who wish to grow their own fruit in a limited space and at the same time add a decorative feature to the garden. A.B.B.

COCOA. By D. H. URQUHART. (London : Longmans, Green. Tropical Agriculture Series. 1955. Pp. 230, illus. Price 35s. od.)

Changes in the cocoa industry during the last 30 years or so have made the best of the old standard texts look old-fashioned and the need for a fresh review of knowledge about the crop has been evident for some time. Many factors have contributed to the changes, including the results of intensive research, which has moved fast after a late start. The most fundamental is the tendency of world consumption to increase faster than production. This, accentuated by the threat to supplies from the spread of several particularly damaging diseases and pests, has brought about a change of outlook throughout the industry significantly expressed in an increasing interest shown by the manufacturing side in the producing side. It is indeed largely to that interest that the research and its results are due.

Mr. Urquhart is well qualified to write on current practice in cocoa production and to present a broad view of the industry as a whole. A former Director of Agriculture in the Gold Coast, with long experience of cocoa problems in West Africa, he has, since 1950, had unique opportunities of travelling in most of the other cocoa-growing countries of the world, including the older ones and several very new ones which may be important producers in the future. His avowed aim is to provide information which will be of practical use to the planter, and in this he has undoubtedly succeeded.

About a third of the book is devoted to operations on the cocoa plantation, from choice of site to preparation of the crop for market. Other chapters deal with botany, climate, soils, peasant production, rehabilitation of old plantations, pests and diseases, grading of produce, research, and world production and consumption. For several of these chapters Mr. Urquhart has enlisted the aid of specialists. The account of the botany of cocoa by the late Professor R. E. D. Baker presents modern views on varieties concisely and well. Professor F. Hardy contributes the chapter on cocoa soils, Professor C. Y. Shephard that on rehabilitation of old plantations in Trinidad, and Dr. A. F. Posnette that on virus diseases of cocoa. Each of these names assures the most authoritative presentation that could have been chosen. In addition, among noteworthy features of the volume, the author's very full treatment of vegetative propagation, based on published and unpublished work by Dr. H. Evans, must be mentioned. The inclusion of a chapter in which the main centres of research are mentioned, with brief descriptions of their histories, programmes and achievements, is refreshing and valuable.

With these features and a well chosen list of references at the end of each chapter, the book will be useful to some scientists in tropical agriculture as well as to the planters to whom it is primarily addressed. The crop breeder, however, will be disappointed ; the genetical aspects of cocoa production are scarcely mentioned and only scattered remarks indicate that they exist. Some connected account, even if brief, of variability in cocoa-tree populations, the results of early selections and the aims of cocoa breeders would have improved the balance of the work even for the practical planter who in these days is interested in material as well as in methods. The uninitiated might possibly conclude, after reading the whole book, that it does not much matter what he plants so long as it is cocoa.

The book has more than a hundred good illustrations, most of them making definite points and others conveying very well the conditions under which cocoa is grown and prepared for market. E.E.C.

PUBLICATIONS RECEIVED.

BRITISH WEED CONTROL COUNCIL. PROCEEDINGS OF THE BRITISH WEED CONTROL CONFERENCE, 1954, HARROGATE. (1955. Vols. 1 and 2. Pp. 550+73. Price 30s. 0d.)

Papers are included on herbicidal work in vegetable crops in Denmark and in bulb crops, on pre-emergence treatment of vegetables and on several aspects of the weed problem in peas. Otherwise there is little that is specifically horticultural.

DAS FROSTPROBLEM IM OBSTBAU. (Frost problems in fruit growing.) By E. KEMMER and F. SCHULZ. (Munich : Bayerischer Landwirtschaftsverlag. 1955. Pp. 96, bibl. 6, illus. Price DM.6·90.)

In their comprehensive and critical review, published on the occasion of the 25th anniversary of the founding of the Institut für Obstbau, Berlin, the authors survey the manifold frost problems in fruit growing under the following headings : *A. Spring frost :* general remarks ; the effect of frost ; frost incidence and locality ; frost protection ; *B. Winter injury to the wood and root :* general remarks ; definition of the term " severe winter " ; history of noteworthy winters ; physico-chemical and physiological processes in the plant ; loci of frost damage ; the influence of tree condition and locality on frost resistance ; responses of species, varieties, rootstocks and stembuilders ; the question of freezing trials.

ROCK GARDENING. By G. K. MOONEY. (London : W. H. & L. Collingridge Ltd. 1955. Pp. 92, illus. Price 3s. 6d.)

PLANT PROTECTION BULLETIN, Volume III, No. 3. Food and Agriculture Organization of the United Nations. (London : H.M. Stationery Office. 1954. Pp. 48. Price 1s. 6d.)

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